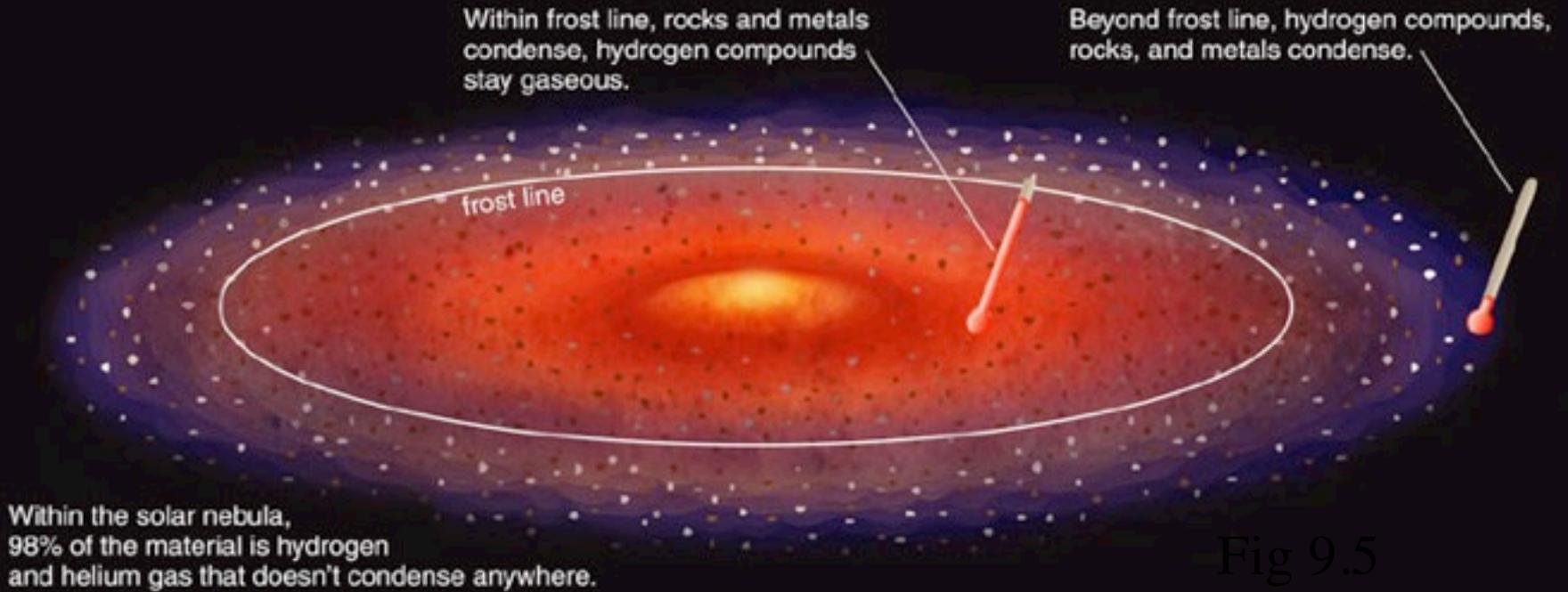


Today

- The Little Things
 - Comets
 - Impacts - when asteroids or comets strike
 - Dwarf Planets





FROST LINE at about 3.5 AU

Inside the *frost line*: Too hot for hydrogen compounds to form ices
- only get rocky asteroids and planets

Outside the *frost line*: Cold enough for ices to form
- get icy moons and comets
- ice is a major component of their total mass

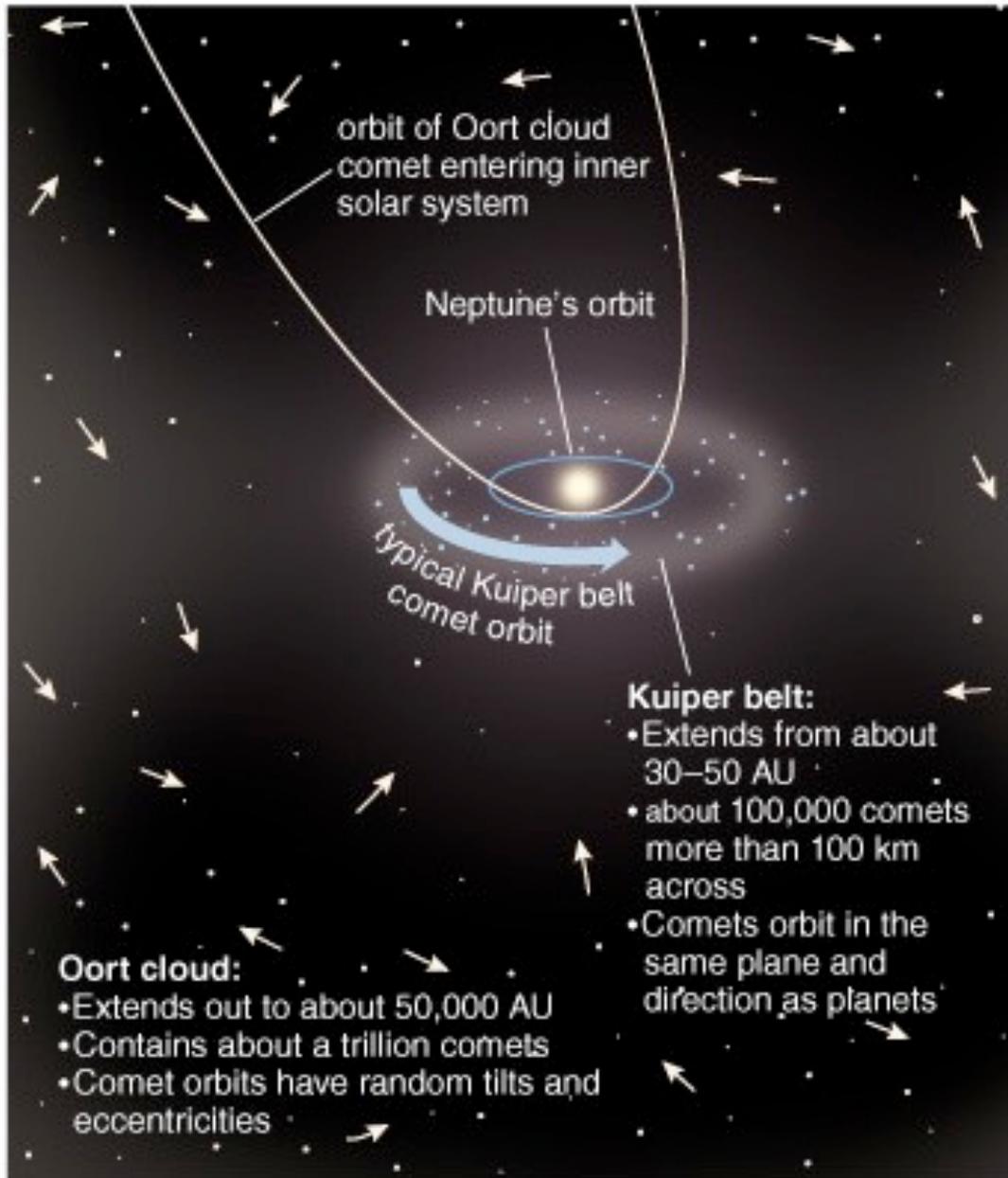
Comets



a Comet Hyakutake.

Comet Facts

- Formed beyond the frost line, comets are icy counterparts to asteroids.
- Nucleus of comet is a "dirty snowball."
- Most comets do not have tails.
- Most comets remain perpetually frozen in the outer solar system.
- Only comets that enter the inner solar system grow tails.
 - i.e., the “apparition” of a comet is its brief-lived summer season while it is near the sun
- Most comets on highly elliptical orbits
 - often highly inclined (out of ecliptic plane)



Only a tiny number of comets enter the inner solar system; most stay far from the Sun.

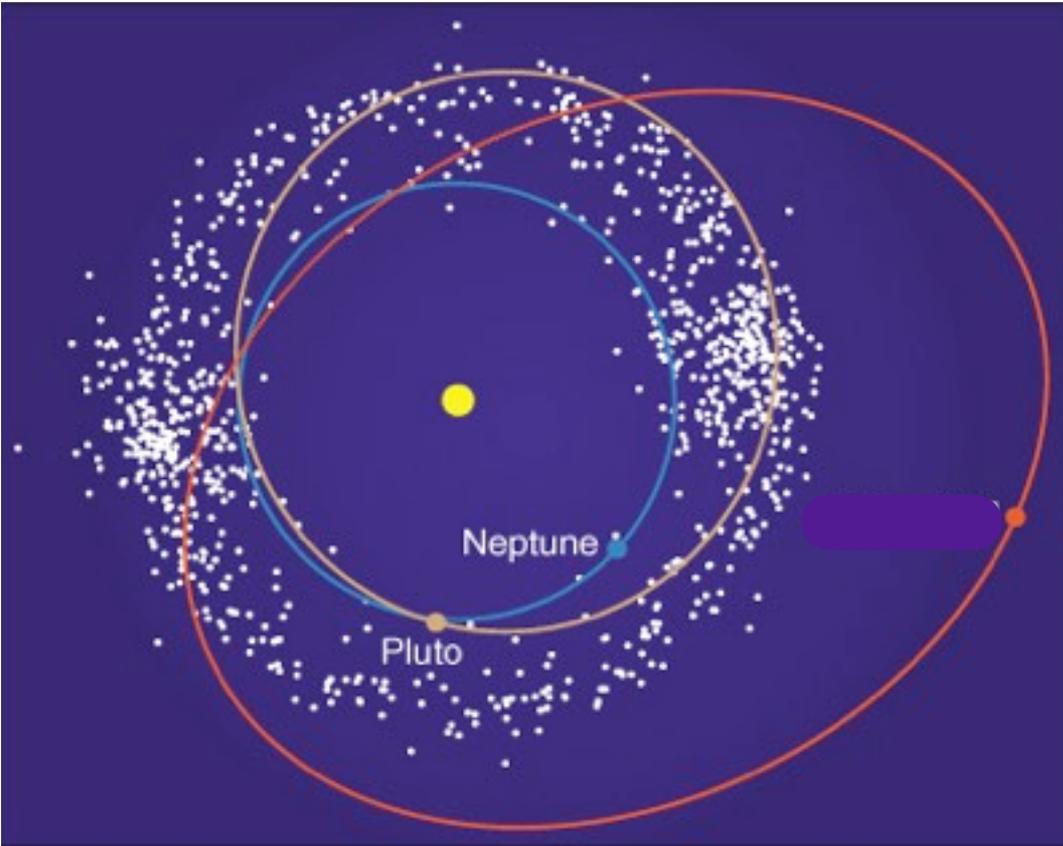
Oort cloud:

On random orbits extending to about 50,000 AU.

Kuiper belt:

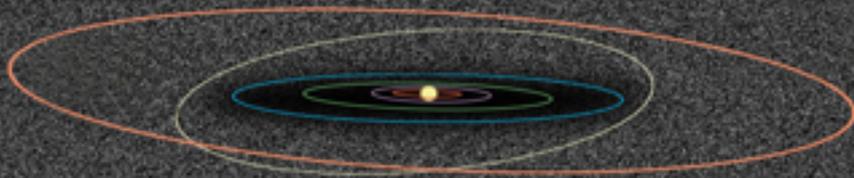
On orderly orbits (mostly in ecliptic plane) from 30–50 AU. Sort of an outer comet belt.

Kuiper Belt

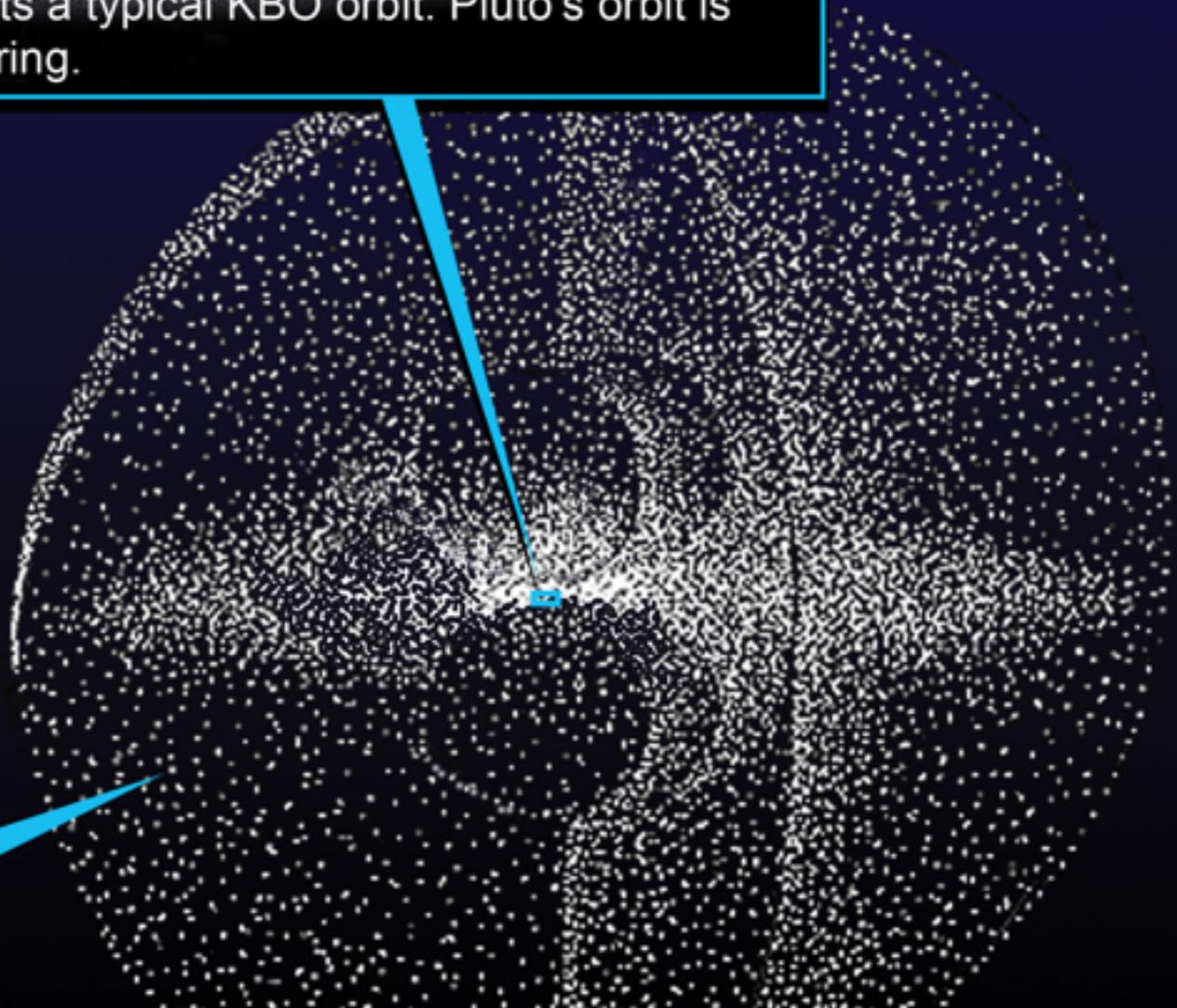


- disk of objects beyond the orbit of Neptune
- Like more distant, icy version of asteroid belt
- Many small objects; some large ones (like Pluto)

Kuiper Belt



The orange track represents a typical KBO orbit. Pluto's orbit is represented by the yellow ring.



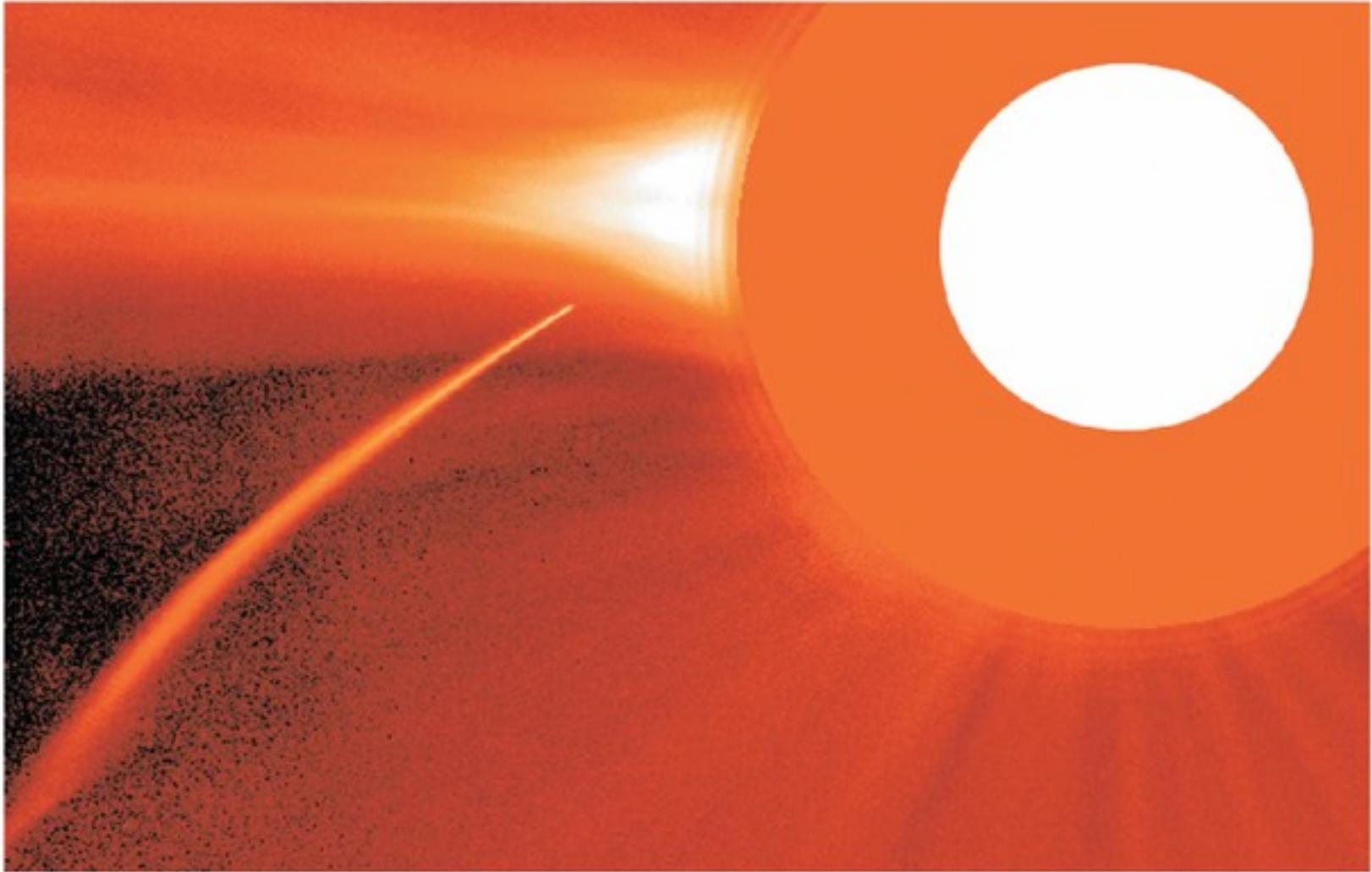
Oort Cloud

How did they get there?

- Kuiper belt comets formed in the Kuiper belt: flat plane, aligned with the plane of planetary orbits, orbiting in the same direction as the planets
- Oort cloud comets were once closer to the Sun, but they were kicked out there by gravitational interactions with jovian planets: spherical distribution, orbits in any direction

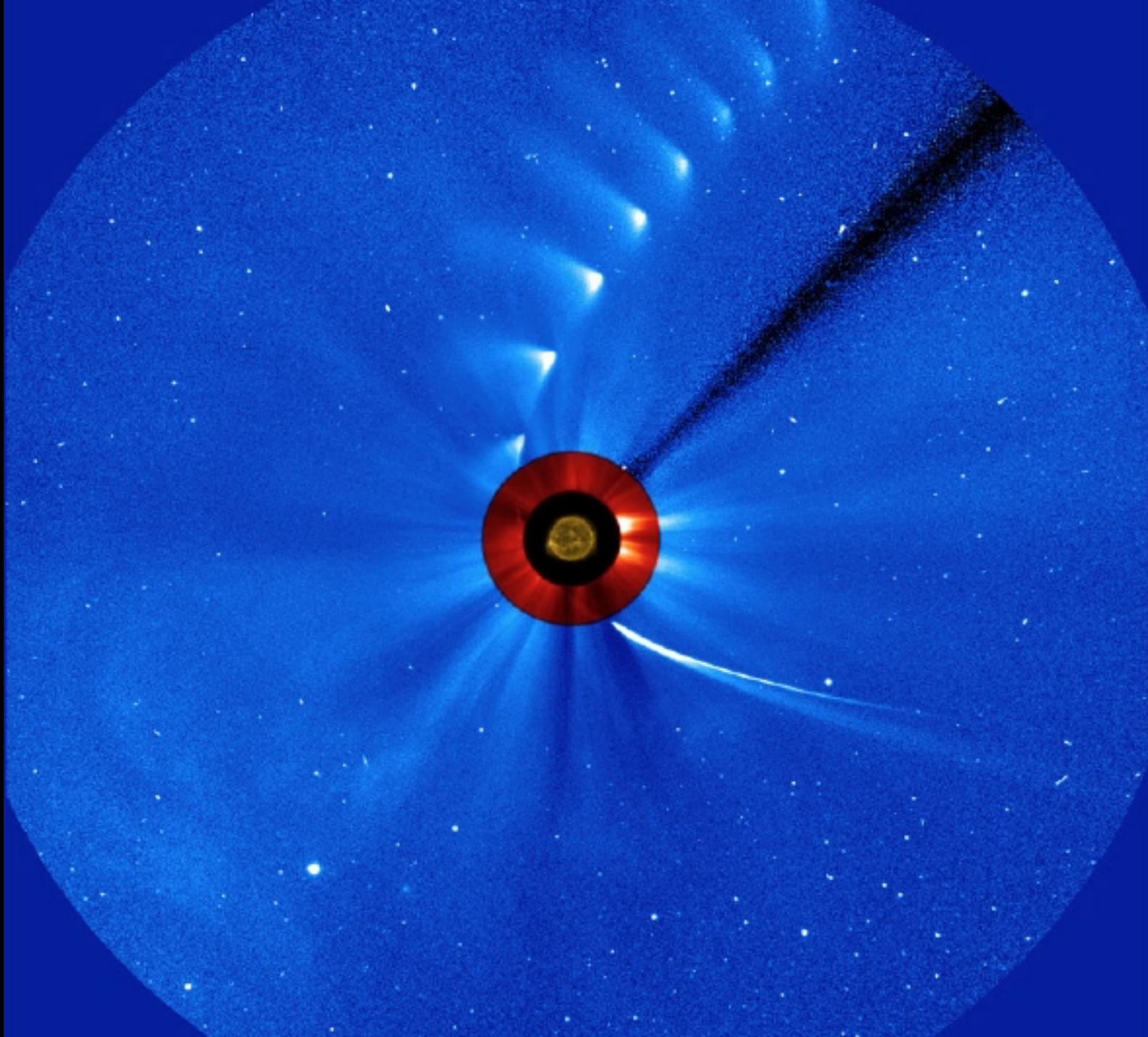
**Jupiter & Neptune -
the great scatterers of the
inner and outer Solar System:**
those objects not absorbed by
planets are ejected by them.

Sun-Grazing Comet

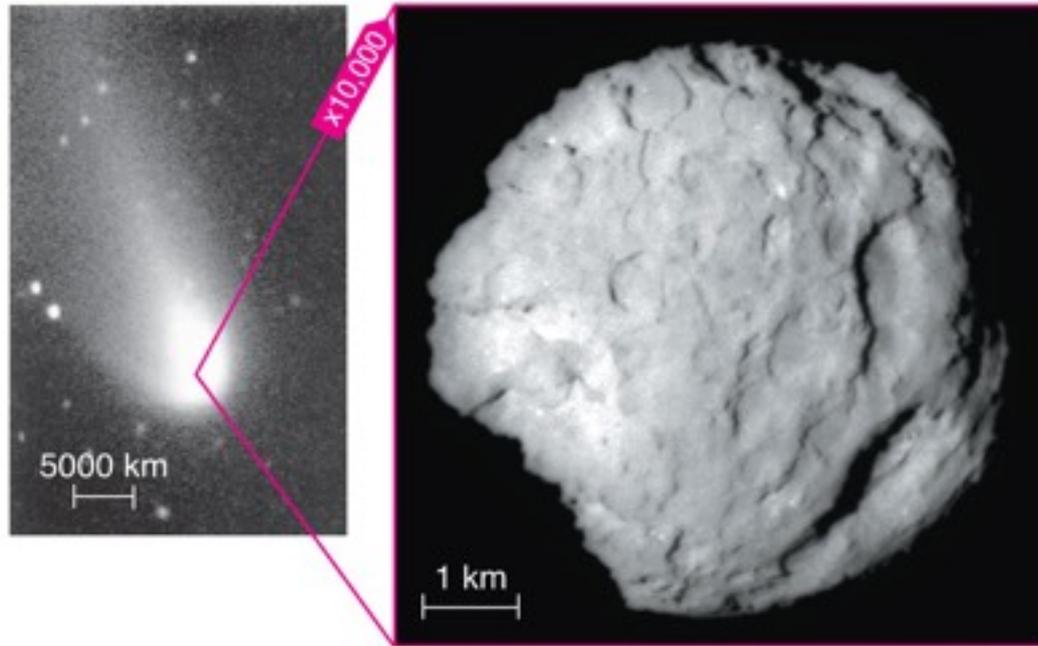


<https://www.youtube.com/watch?v=QJmZlA50DpM>

Time-lapse of a sun grazing comet evaporating



Nucleus of Comet



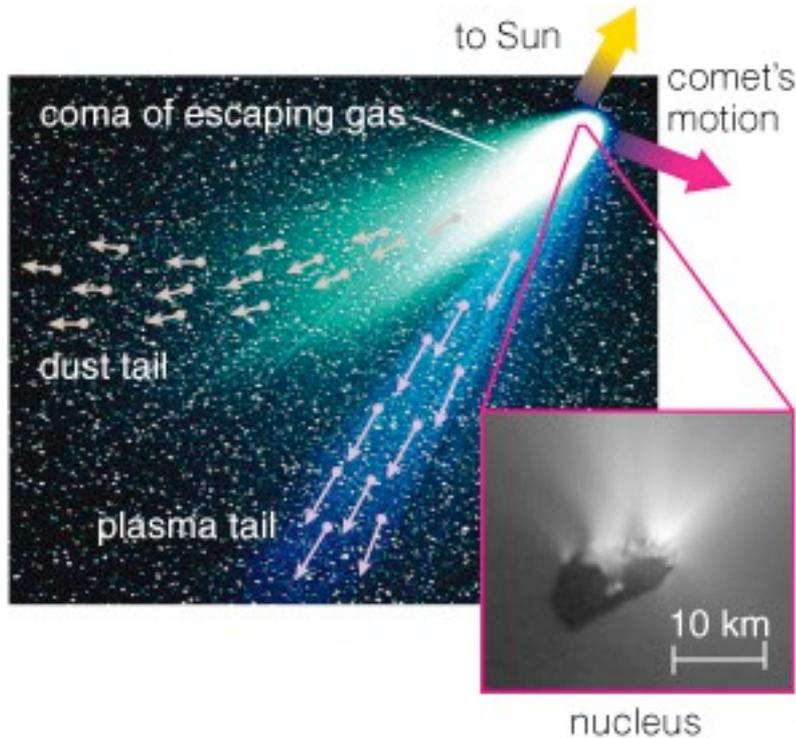
b The first image shows Comet Wild 2 photographed from Earth, and the inset shows its nucleus photographed by the *Stardust* spacecraft. The irregular surface probably shows effects from a combination of impacts and uneven vaporization rates in different regions.

[Interactive Figure](#)

- A "dirty snowball"
 - sort of a fluffy snow cone with a hard shell coated with dust sprinkles
- Composition
 - ice
 - rock
 - carbon rich materials
 - hydrocarbons
 - "tar"
- Source of material for comet's tail

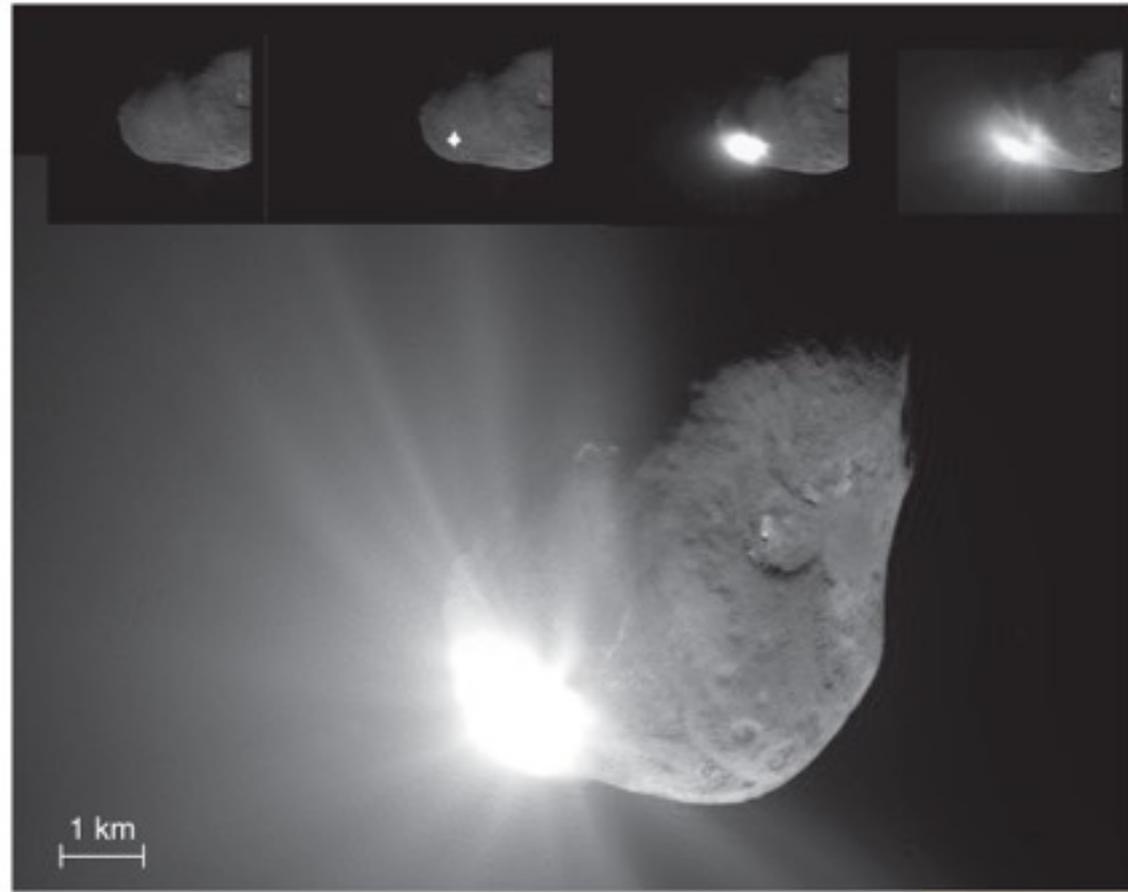
Anatomy of a Comet

- Nucleus: actual object
- Coma is atmosphere that comes from heated nucleus.
- Tail always points away from the sun
 - Plasma tail is gas escaping from coma, pushed by solar wind.
 - Dust tail is pushed by photons.
- Larger debris follow comet's orbit; source of meteoroids.



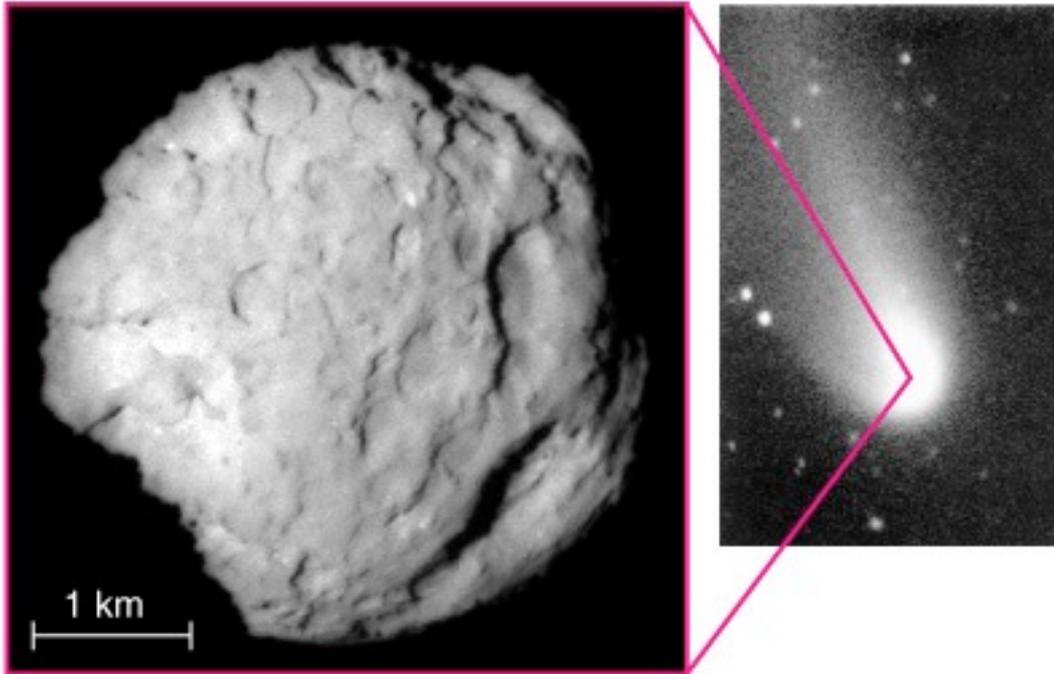
Deep Impact

- Mission to study nucleus of Comet Tempel 1
- Projectile hit surface on July 4, 2005
- Lots of ices (as expected) but also a lot of tarry hydrocarbon materials



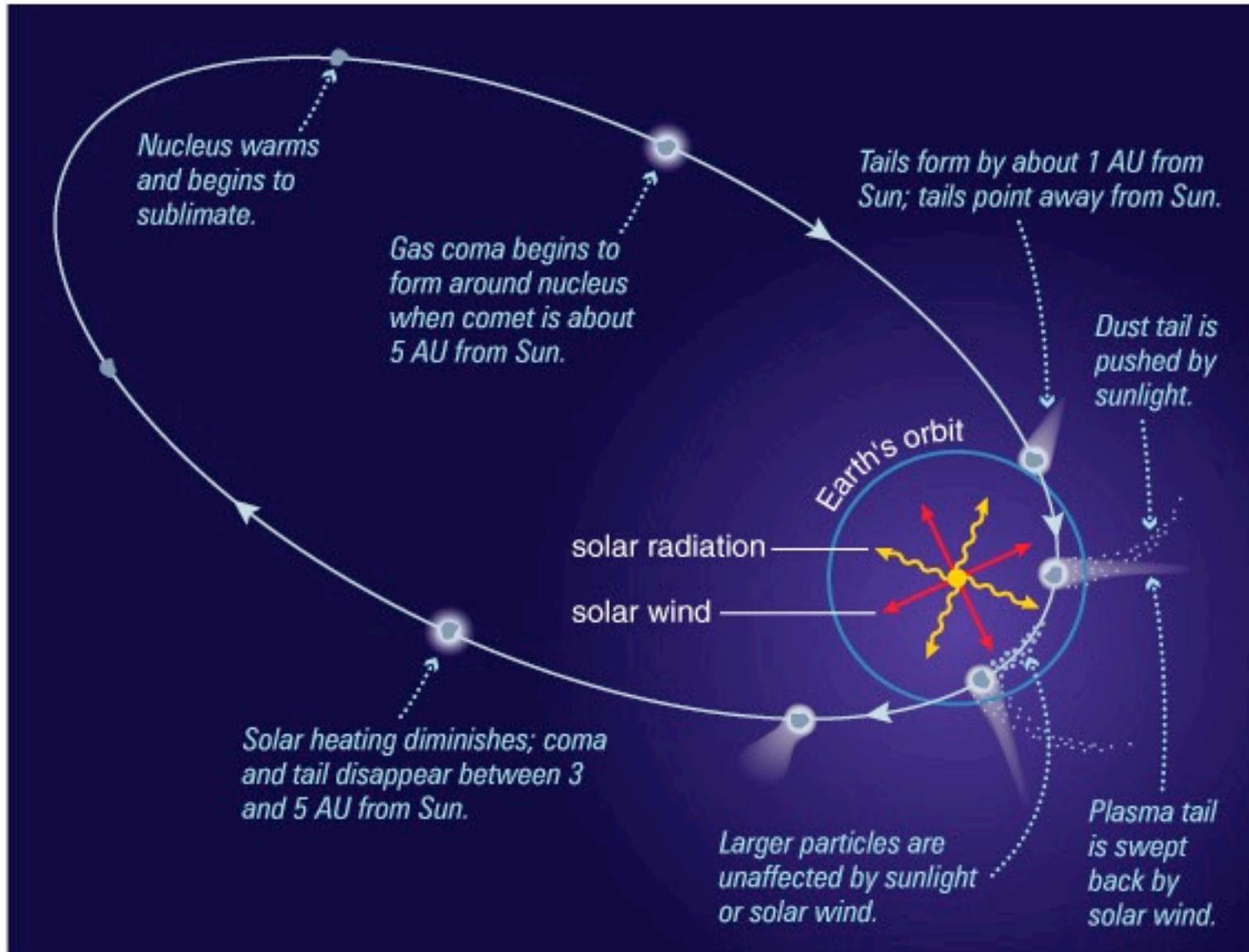
Interactive Figure 

Nucleus of Comet

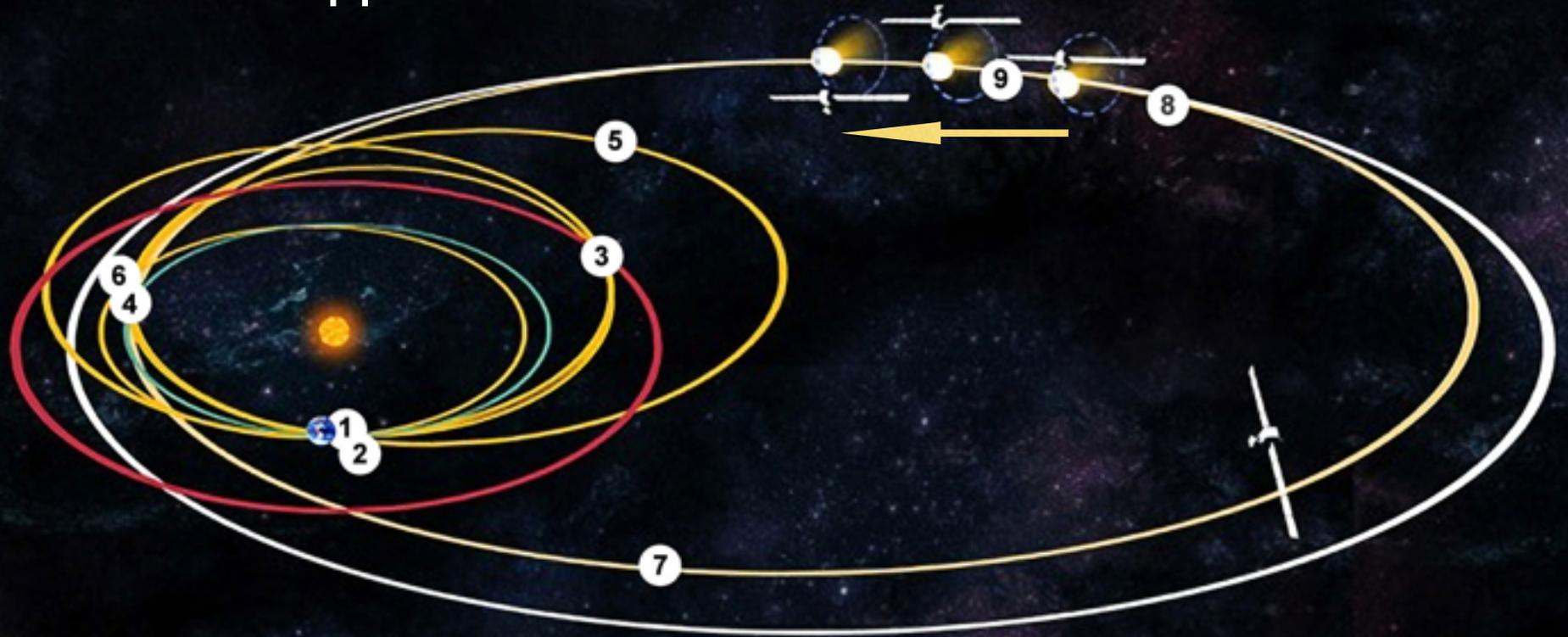


- A “dirty snowball” -
- a combination of rock, ice, and carbon-rich “tar”
- thought to be primitive material unaltered since the formation of the SS
- Source of material for comet’s tail -
- Tail only appears when comet nears the sun: ices are heated into vapor, forming coma and tail.

Growth of Tail



ESA Rosetta mission - launched in 2004; arrived in 2014 as Comet 67P approaches the sun



1. Launch, March 2, 2004

2. First Earth flyby, March 3, 2005

3. Mars flyby, February 26, 2007

4. Second Earth flyby, November 14, 2007

5. Asteroid Steins flyby

6. Third Earth flyby, November 11, 2009

7. Asteroid Lutetia flyby

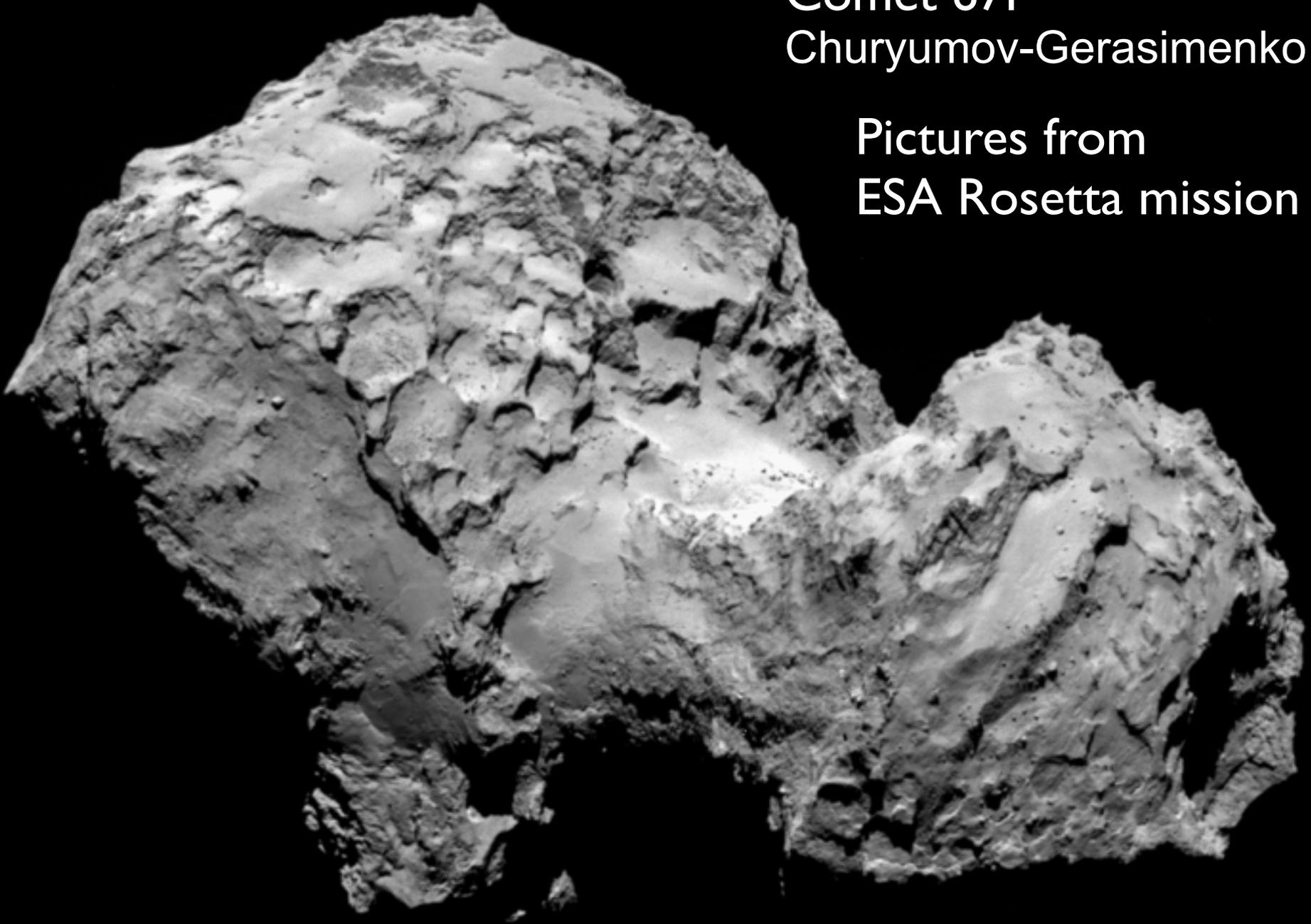
8. Arriving at the comet in 2014

9. Rosetta observes comet 67P/Churyumov-Gerasimenko

● Mars' Orbit ● Earth's Orbit ● Rosetta's Orbit ● Comet's Orbit

Comet 67P
Churyumov-Gerasimenko

Pictures from
ESA Rosetta mission



Comet 67P
4,100 m

Mount Fuji
3,776 m

Mount Olympus
2,917 m

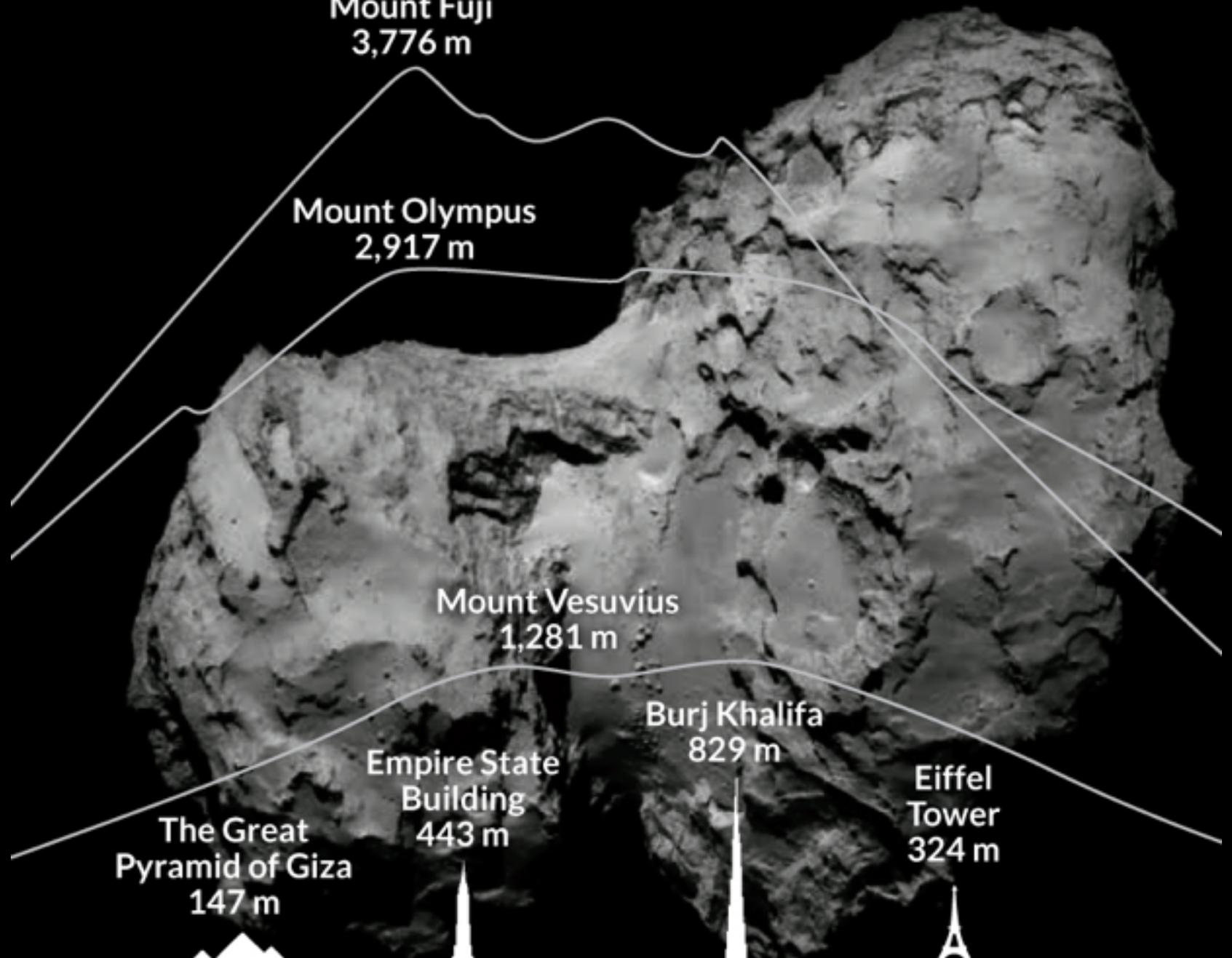
Mount Vesuvius
1,281 m

Burj Khalifa
829 m

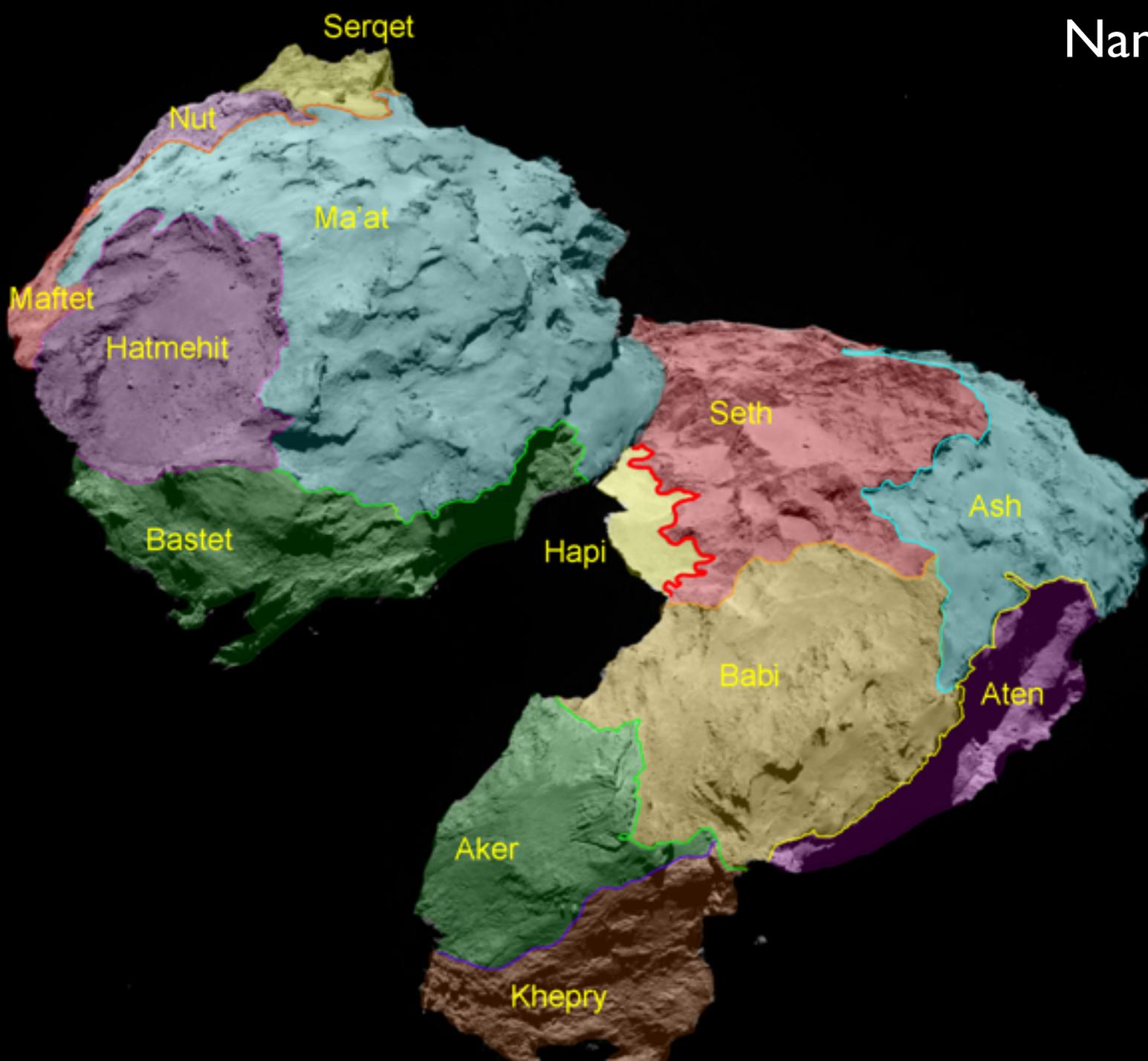
Empire State
Building
443 m

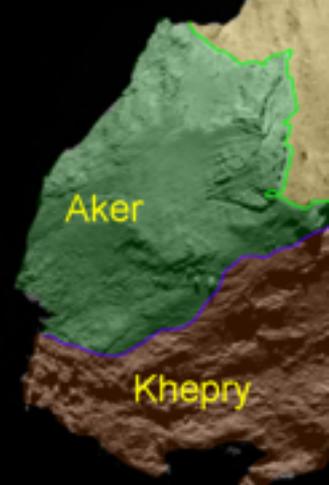
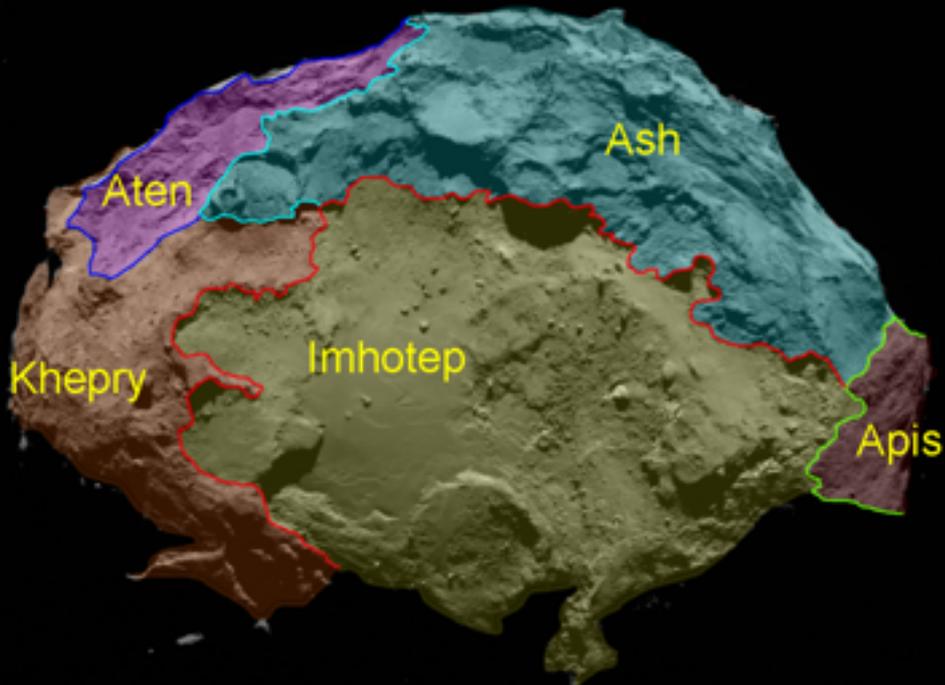
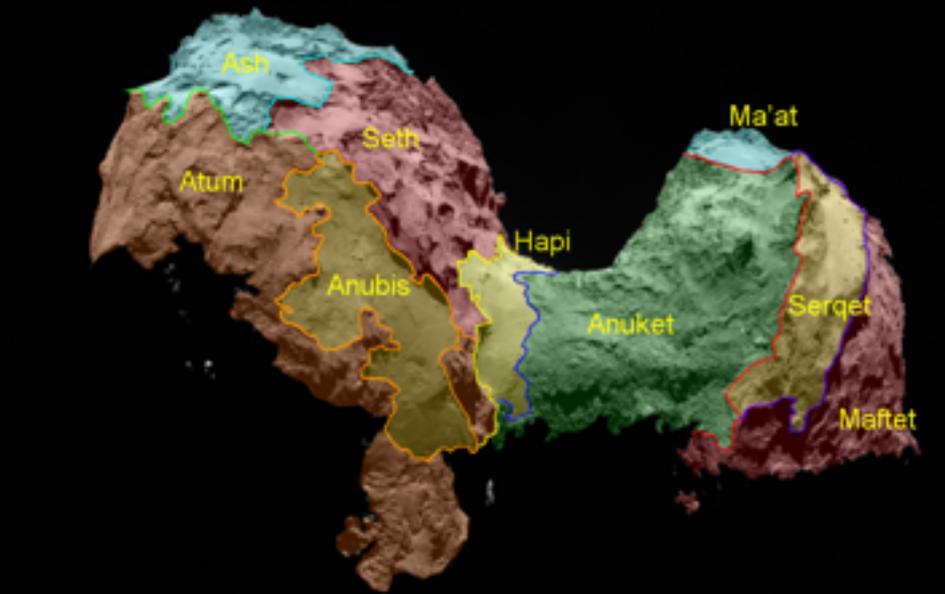
Eiffel
Tower
324 m

The Great
Pyramid of Giza
147 m



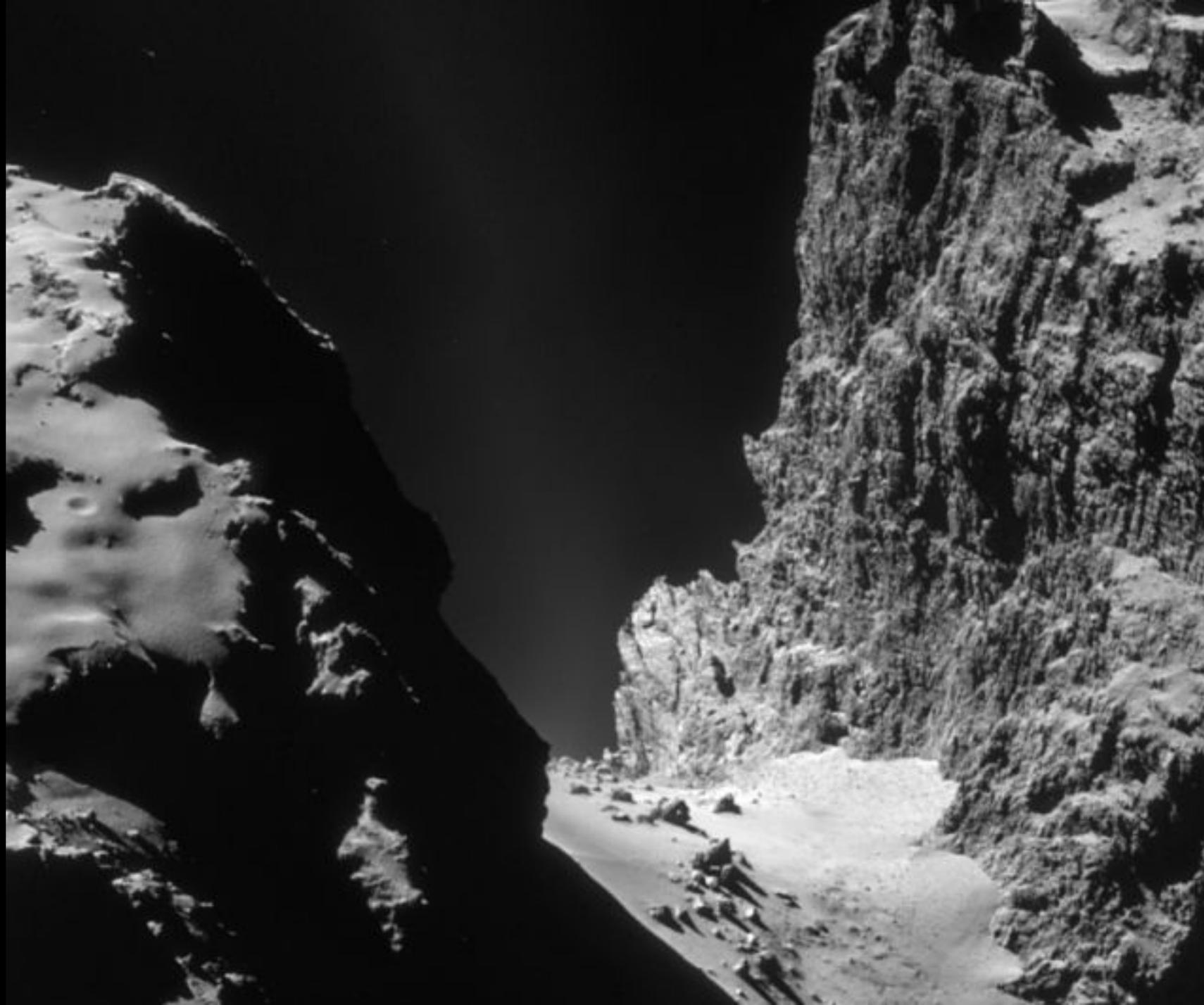
Named regions



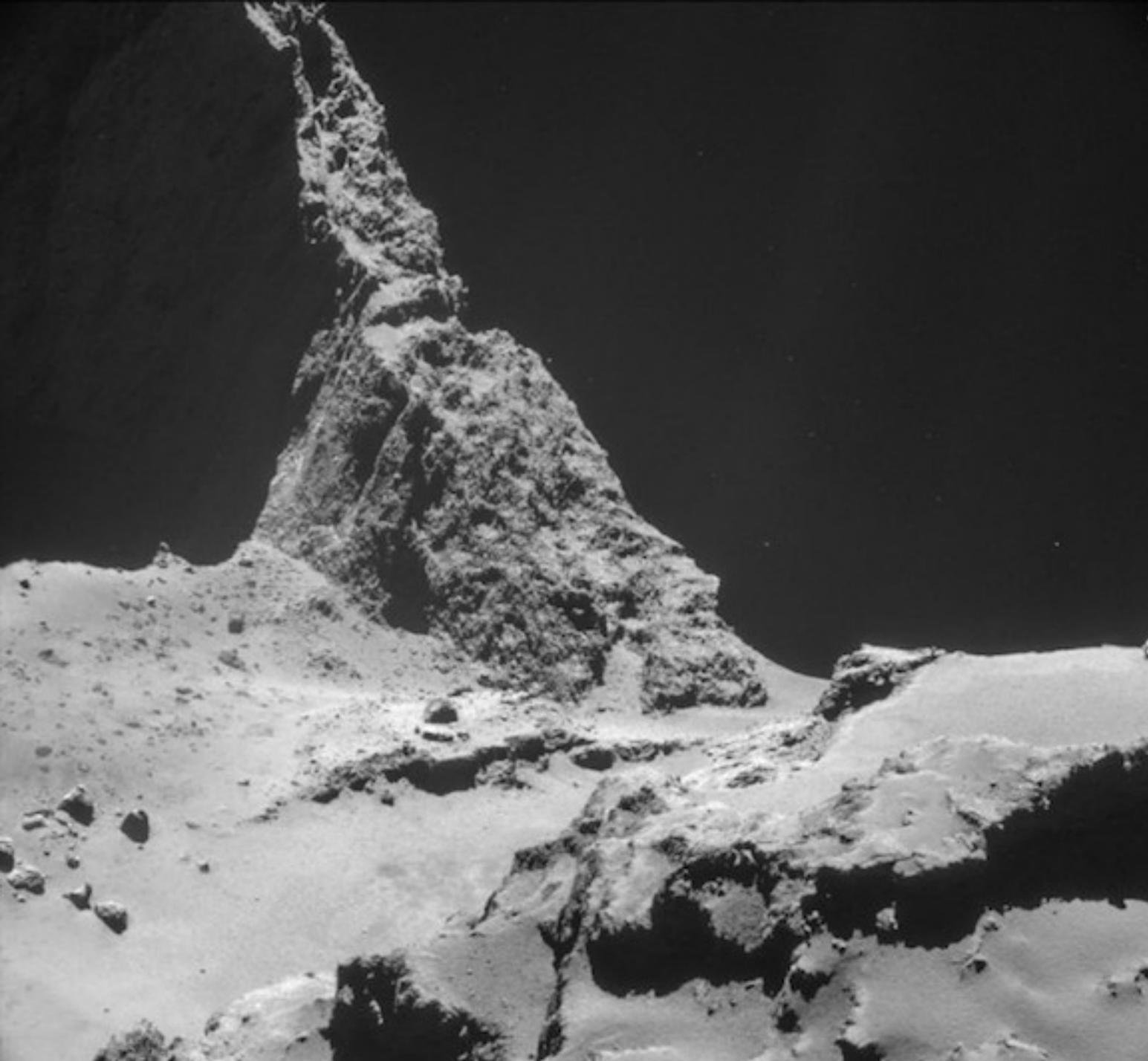


Named regions

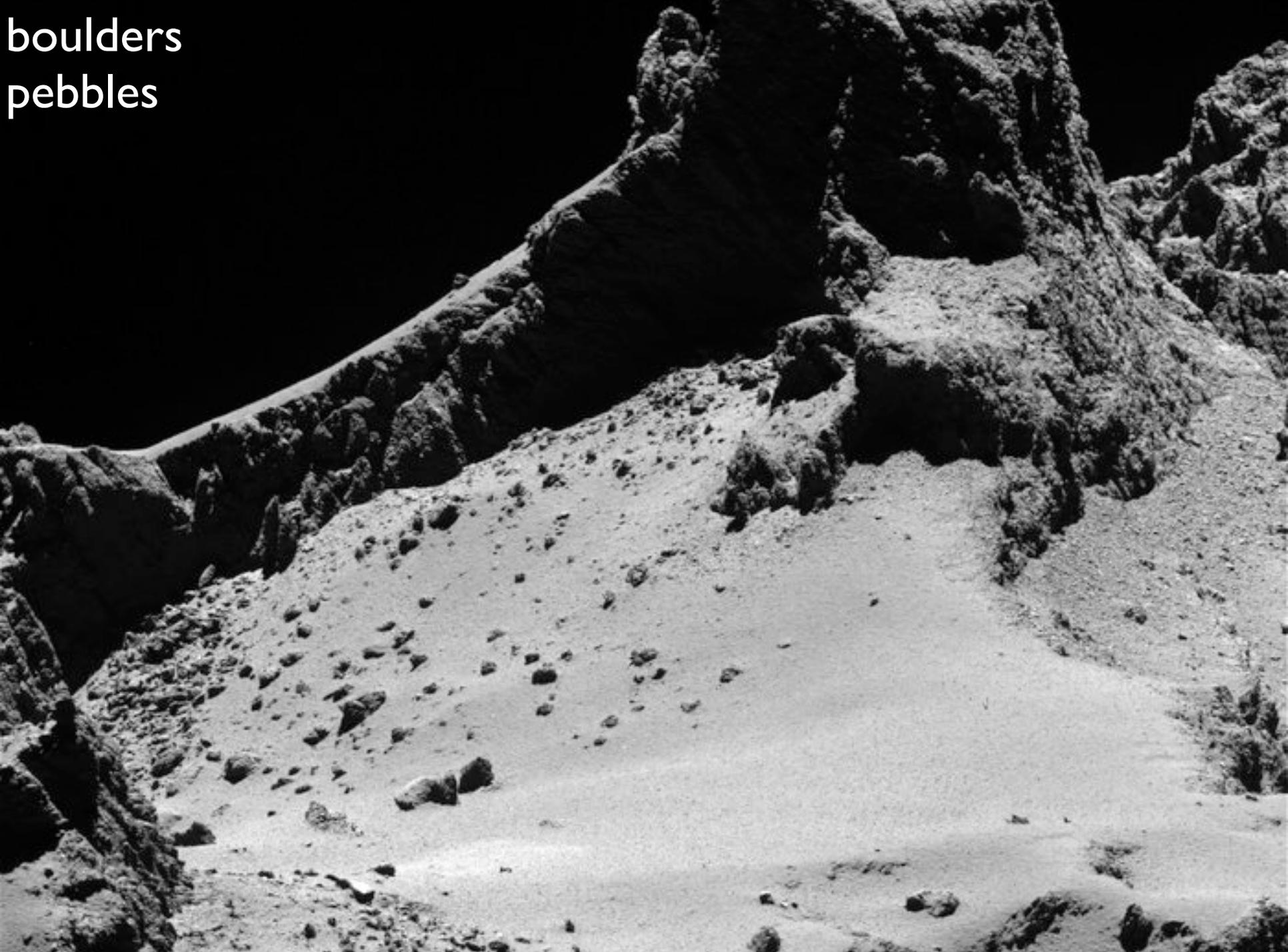
cliffs



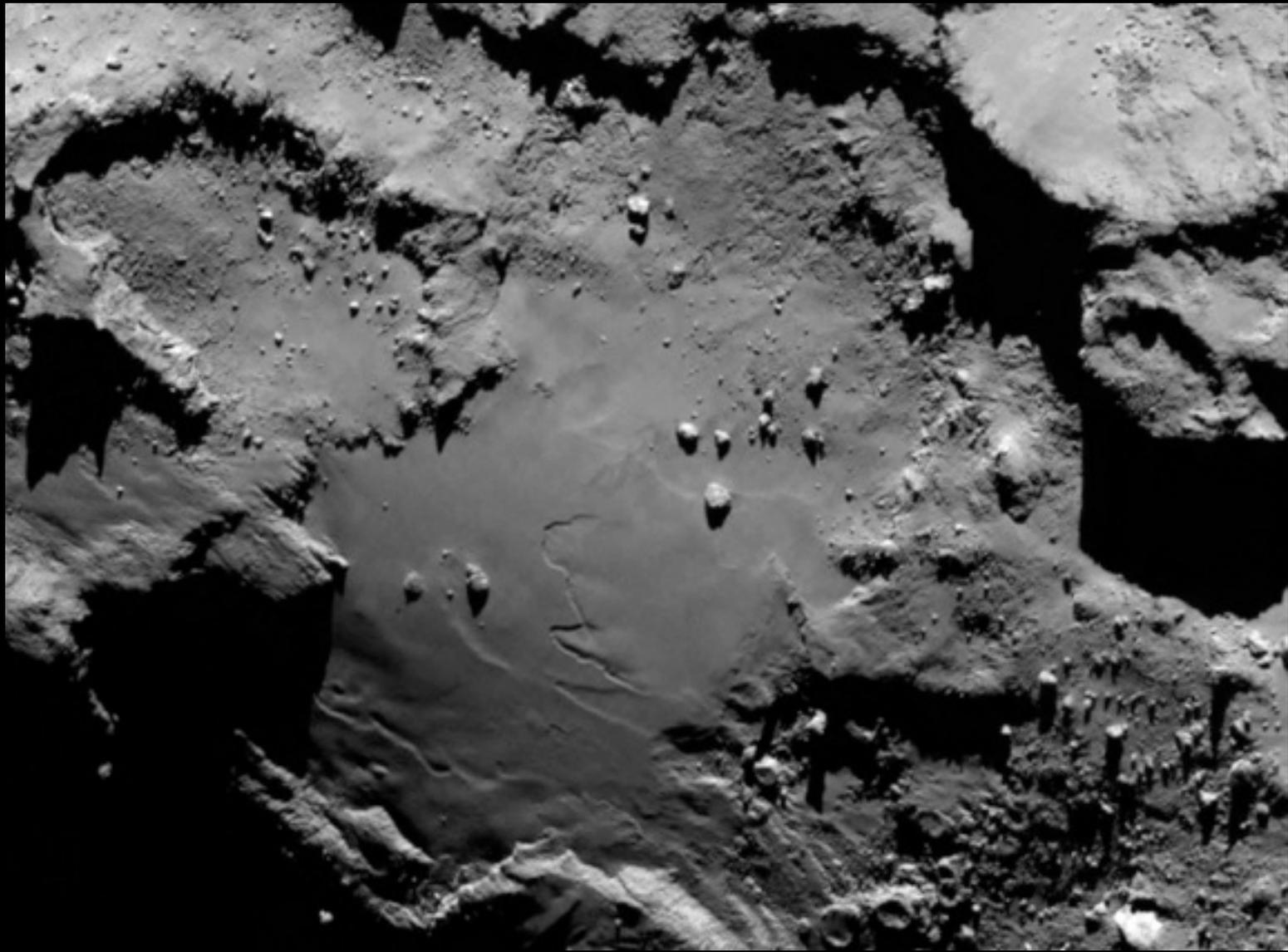
outcrops



boulders
pebbles



sand

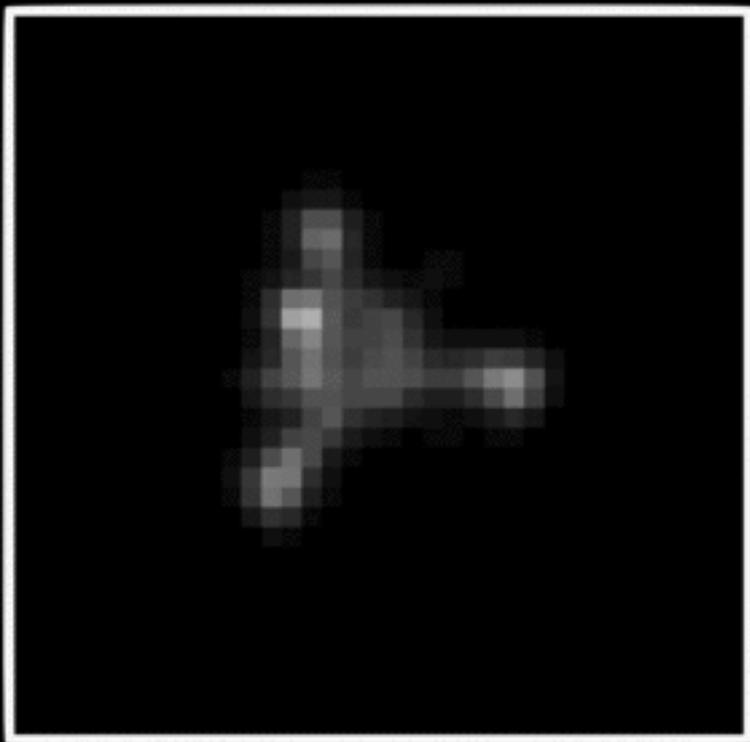


“goosebumps” & sinkholes

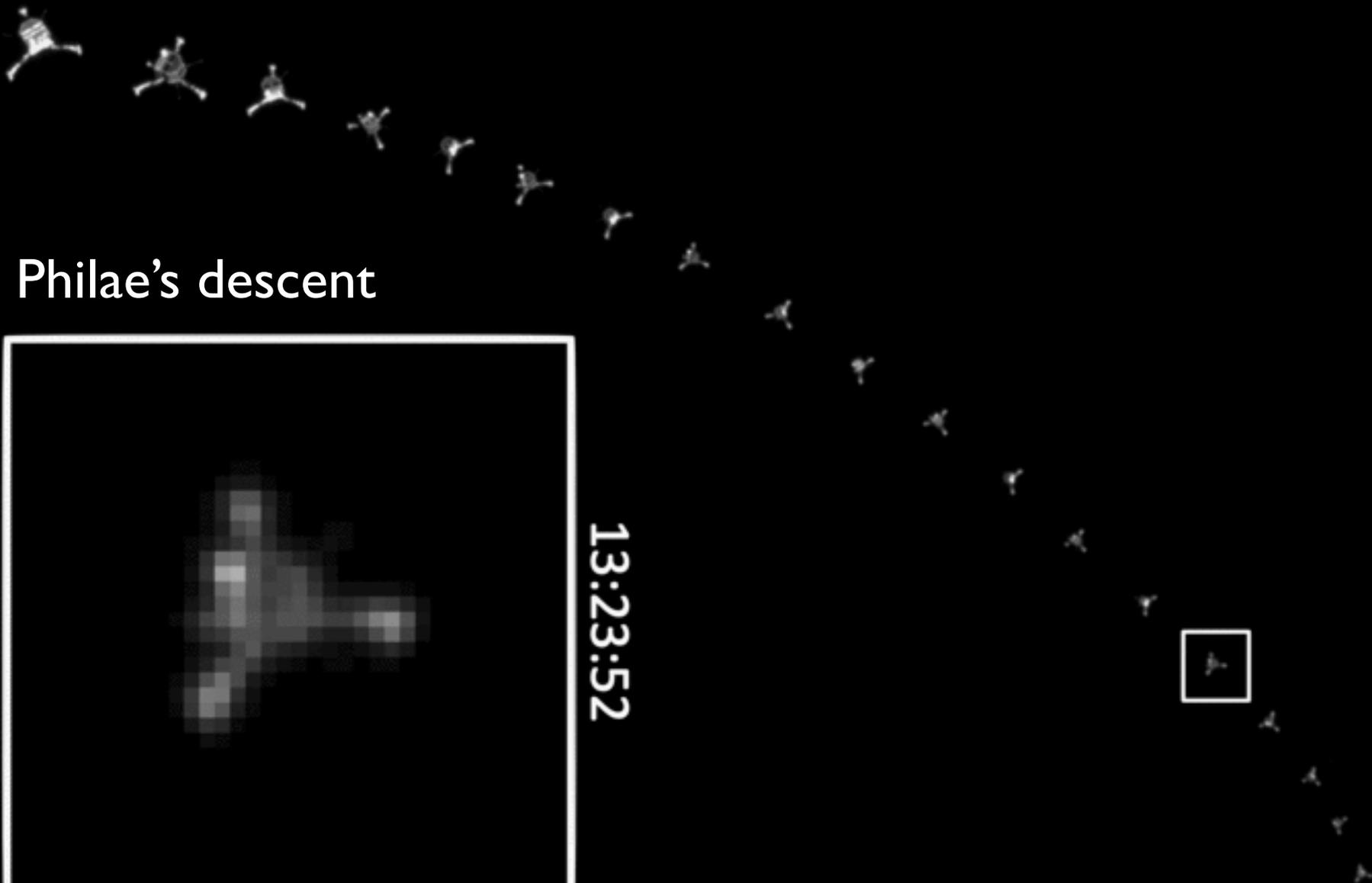


ESA Rosetta mission with Philae lander

Philae's descent



13:23:52



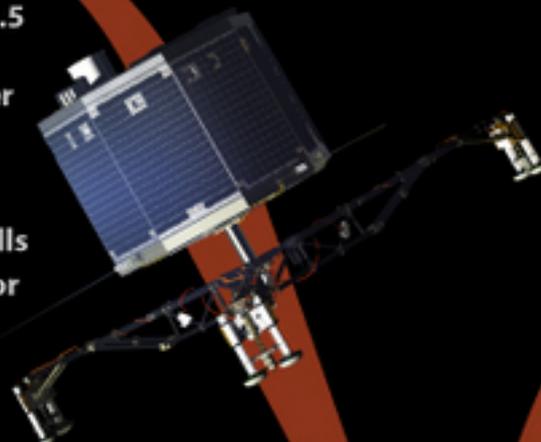
Philae's Bouncy Landing



317 million miles (510 million kilometers) from Earth and 14 miles (22.5 km) from the comet, Rosetta releases lander

When mechanisms intended to secure Philae to the surface of comet 67P failed, the lander bounced back into space twice before settling to rest in partial darkness at the foot of an icy cliff.

Philae lander falls toward comet for 7 hours



Philae travels about 0.6 miles (1 km) up and an equal distance across the comet

Philae hits at 3.3 feet per second (1 meter per second), harpoons and rocket fail to fire

First bounce

HANG TIME: 1 HOUR 50 MINUTES

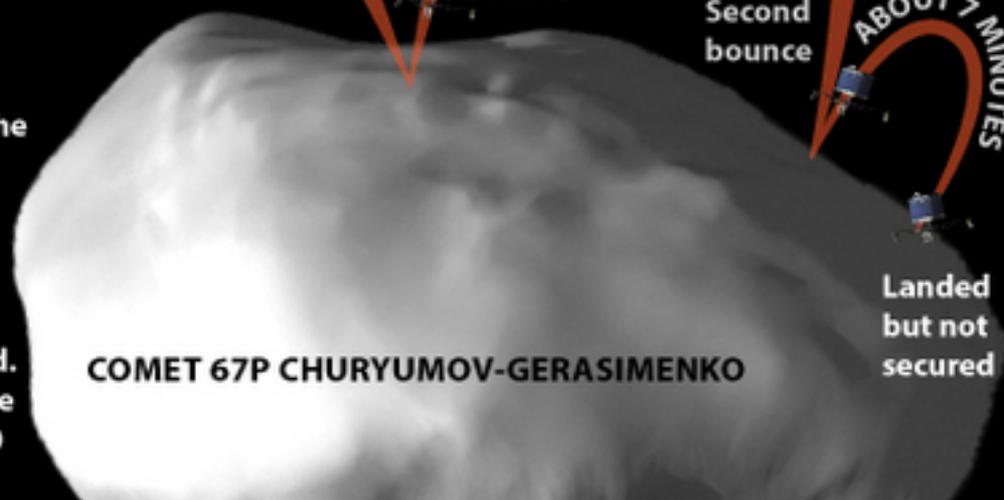
Second bounce

ABOUT 7 MINUTES

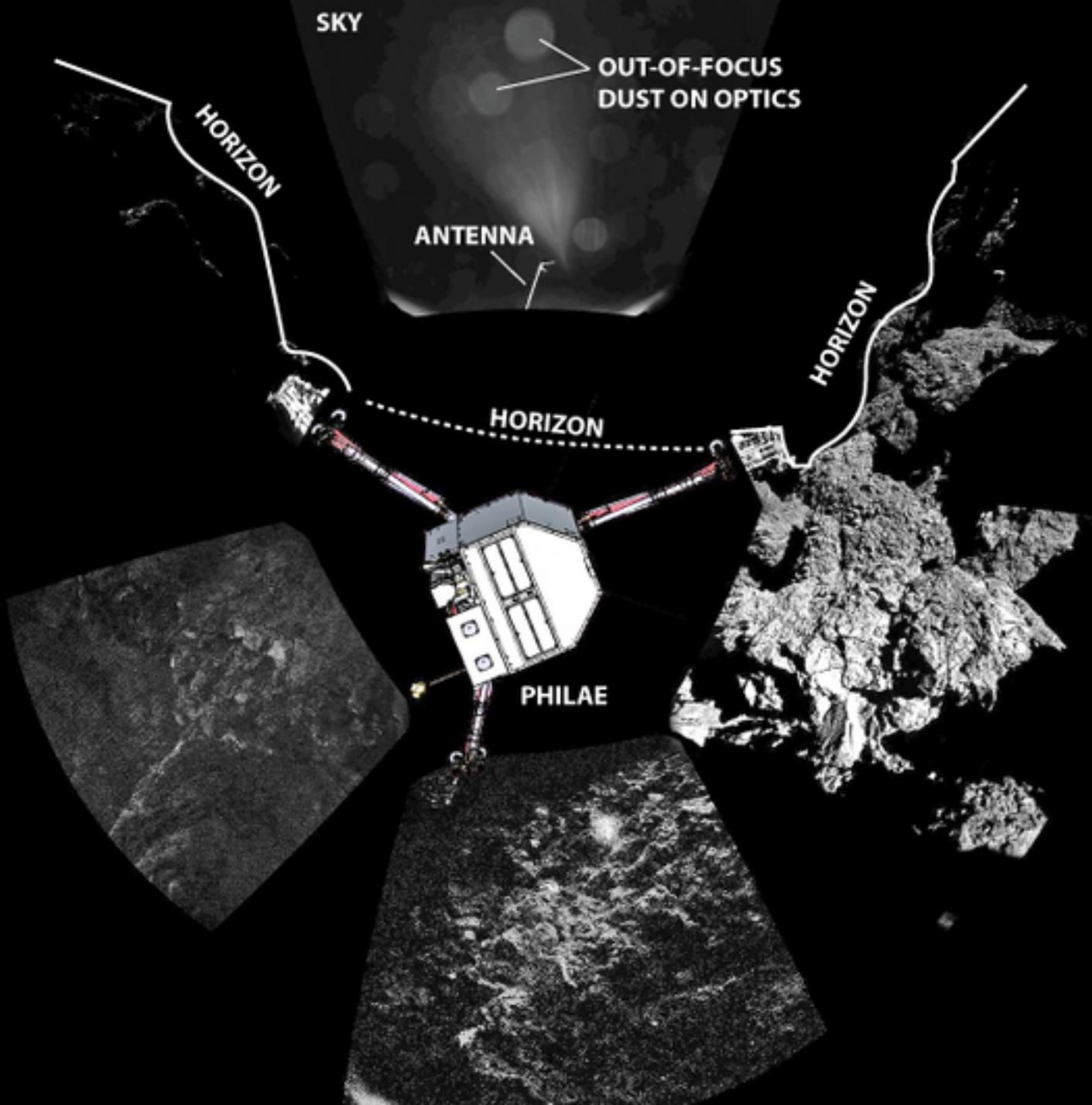
Landed but not secured

- Due to the comet's low gravity, Philae weighs only one gram (about the weight of a paper clip).
- On its first rebound, Philae ascended with a speed of 15 inches (38 centimeters) per second. Escape velocity from the comet is 19.7 inches (50 cm) per second.

COMET 67P CHURYUMOV-GERASIMENKO



Philae's photos of landing spot

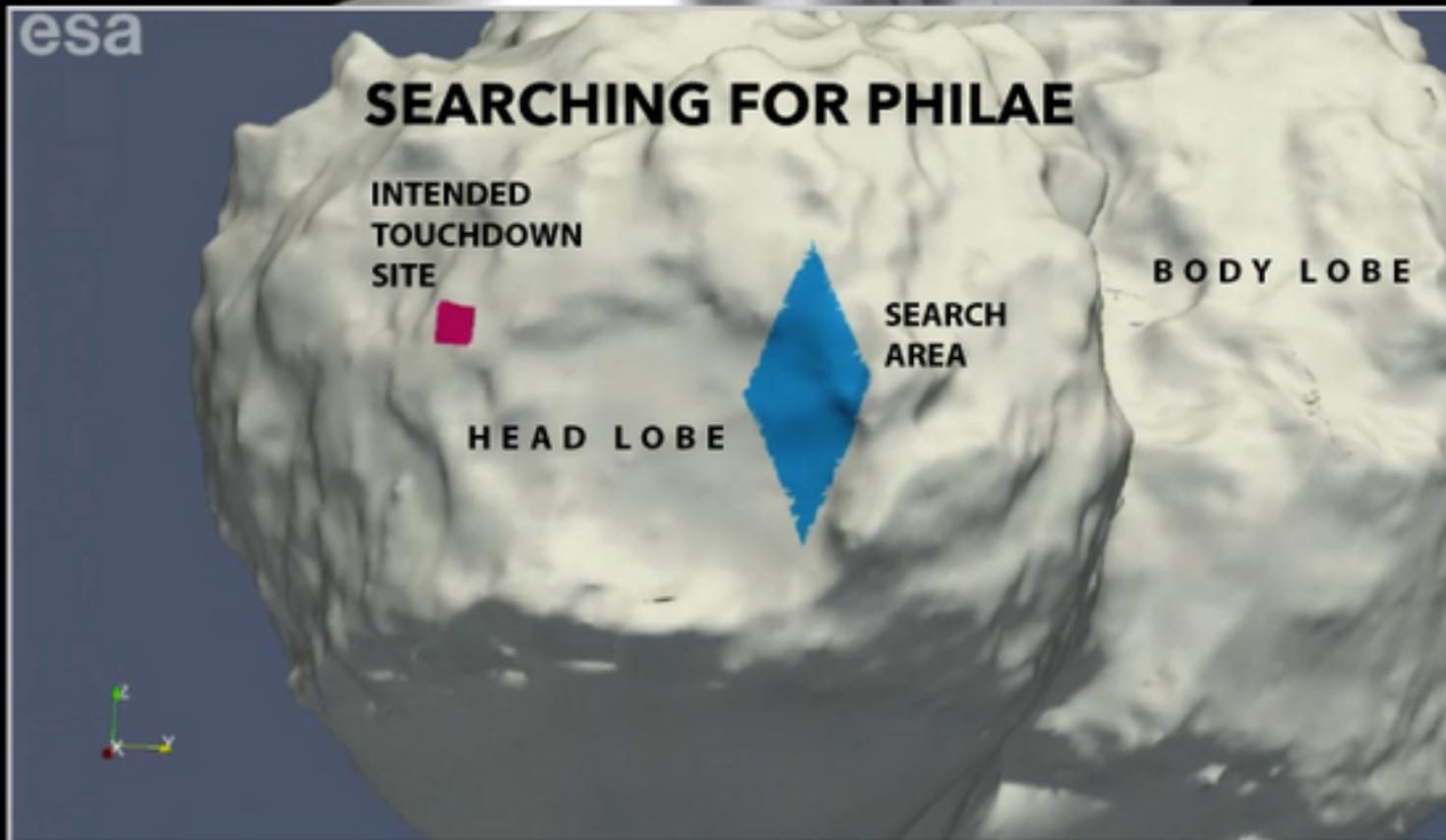


appears to have fallen in deep crevice

- On its first rebound, Philae ascended with a speed of 15 inches (38 centimeters) per second. Escape velocity from the comet is 19.7 inches (50 cm) per second.

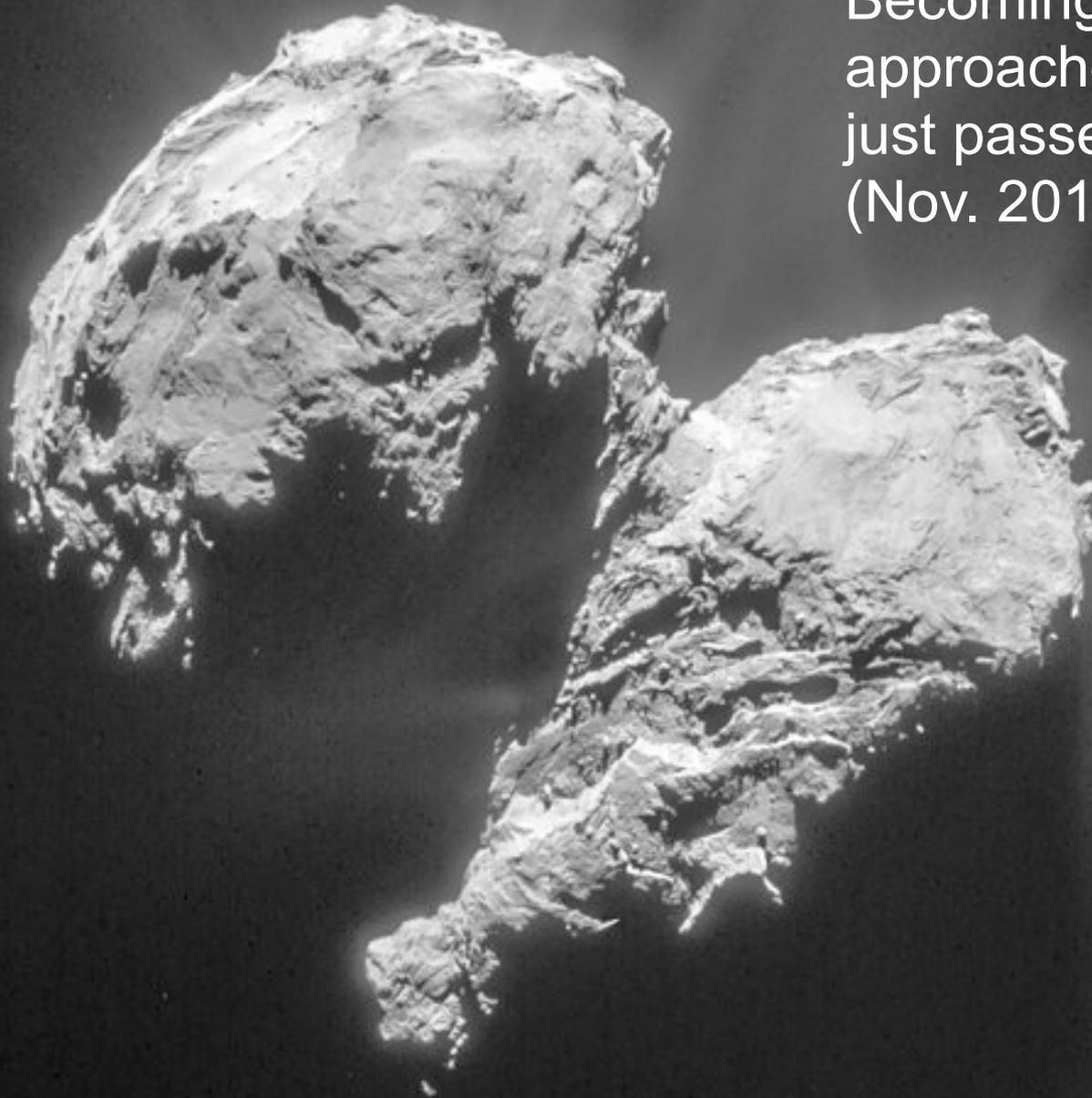
COMET 67P CHURYUMOV-GERASIMENKO

Landed
but not
secured



Comet 67P

Becoming active as it
approaches the sun;
just passed perihelion
(Nov. 2015)



ROSINA has detected many molecules:

Water (H_2O)

Carbon monoxide (CO)

Carbon dioxide (CO_2)

Ammonia (NH_3)

Methane (CH_4)

Methanol (CH_3OH)

Formaldehyde (CH_2O)

Hydrogen sulphide (H_2S)

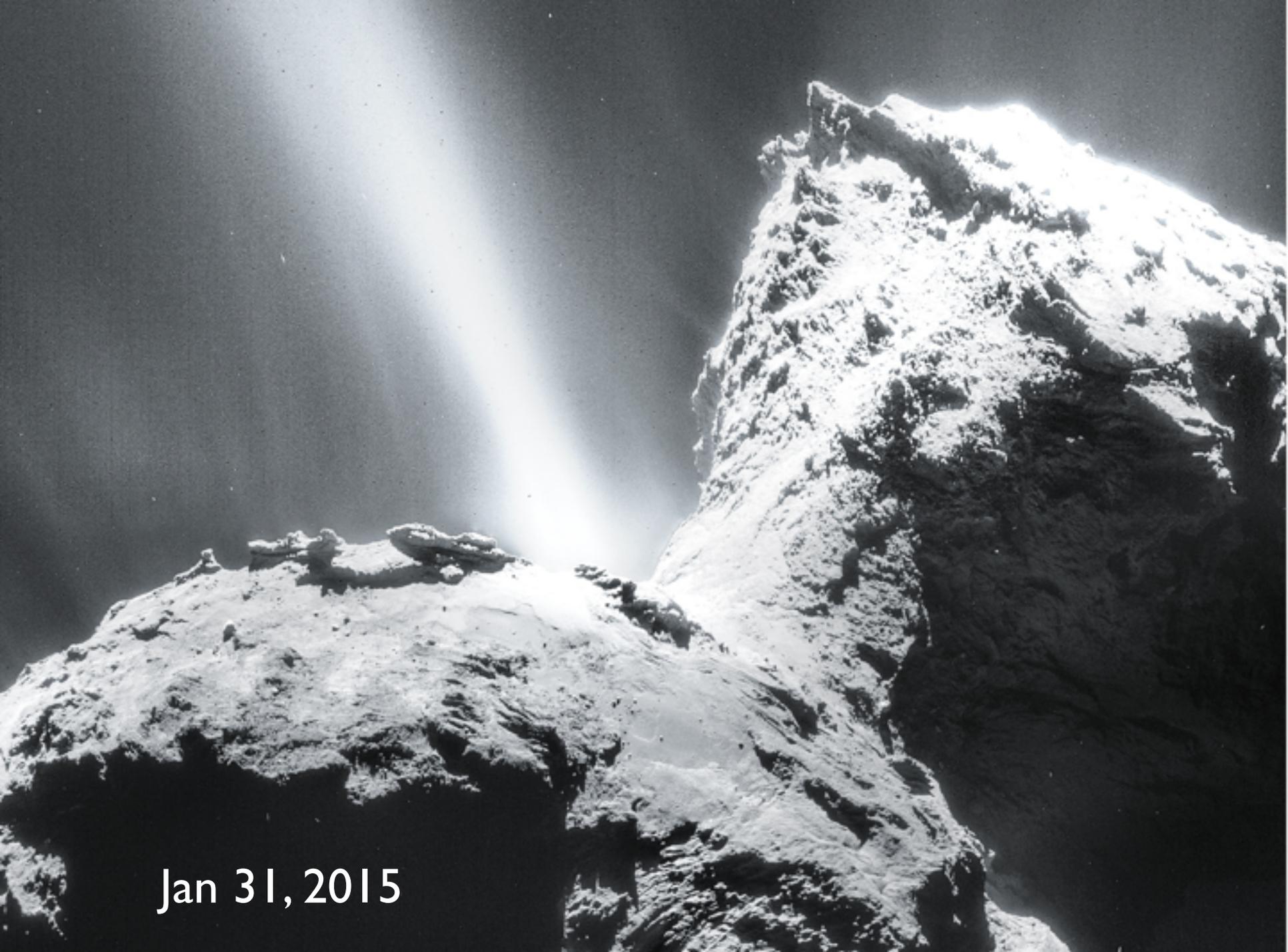
Hydrogen cyanide (HCN)

Sulphur dioxide (SO_2)

Carbon disulphide (CS_2)

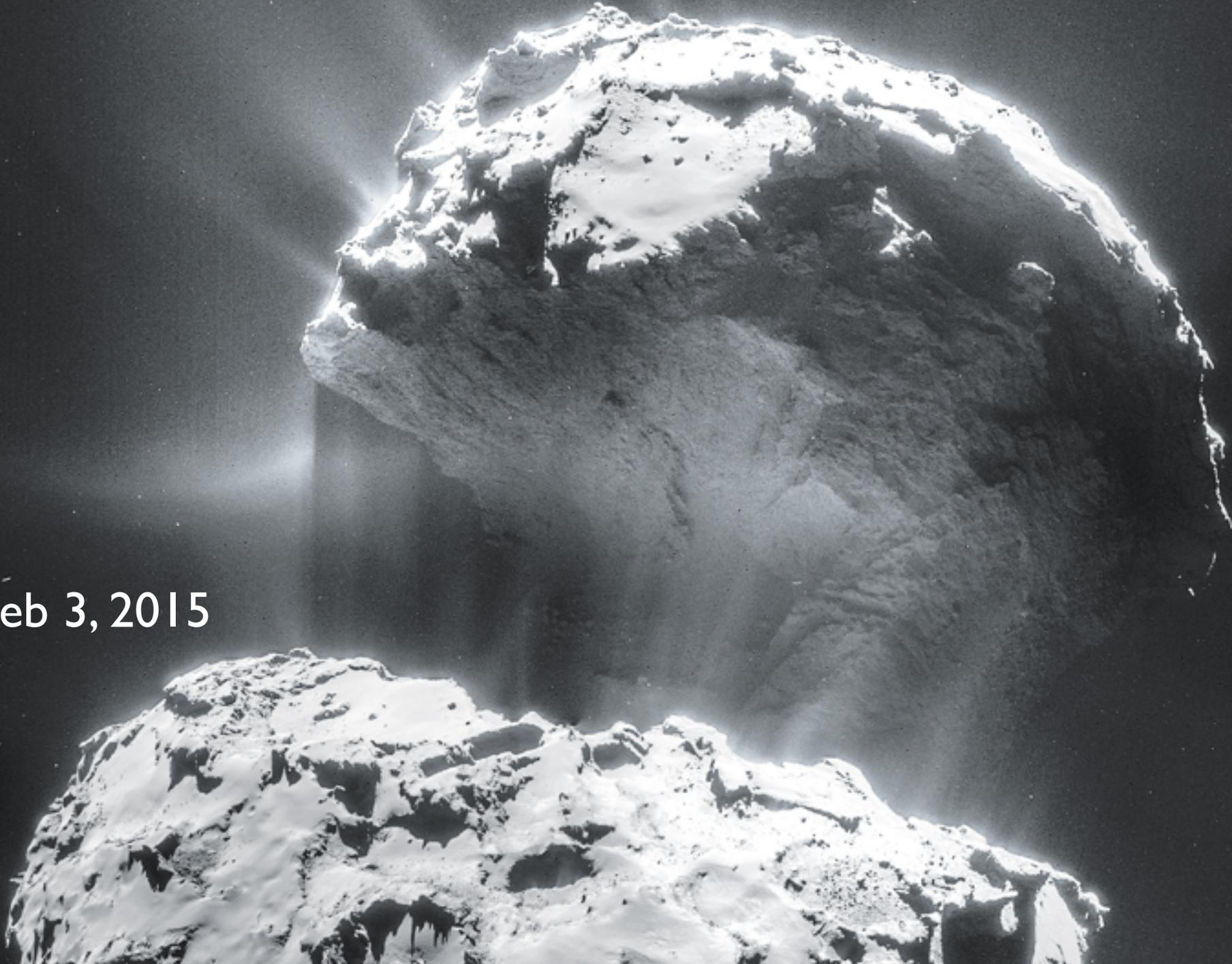


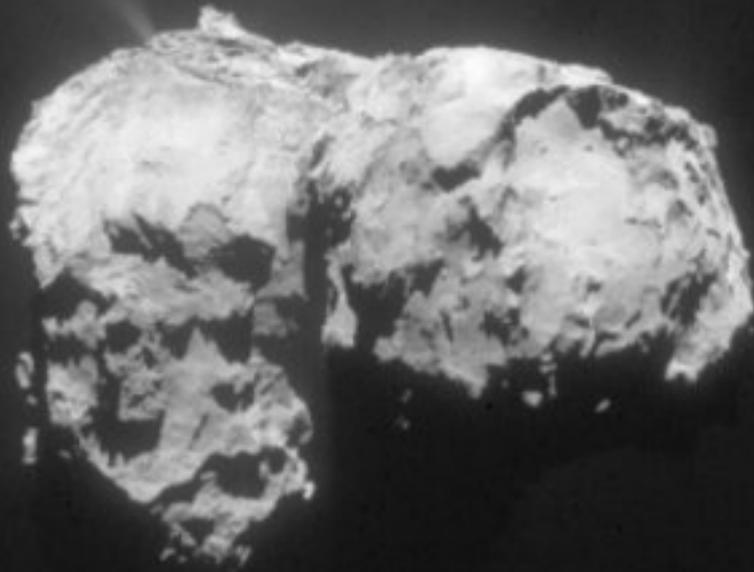
Nov 22, 2014



Jan 31, 2015

Feb 3, 2015





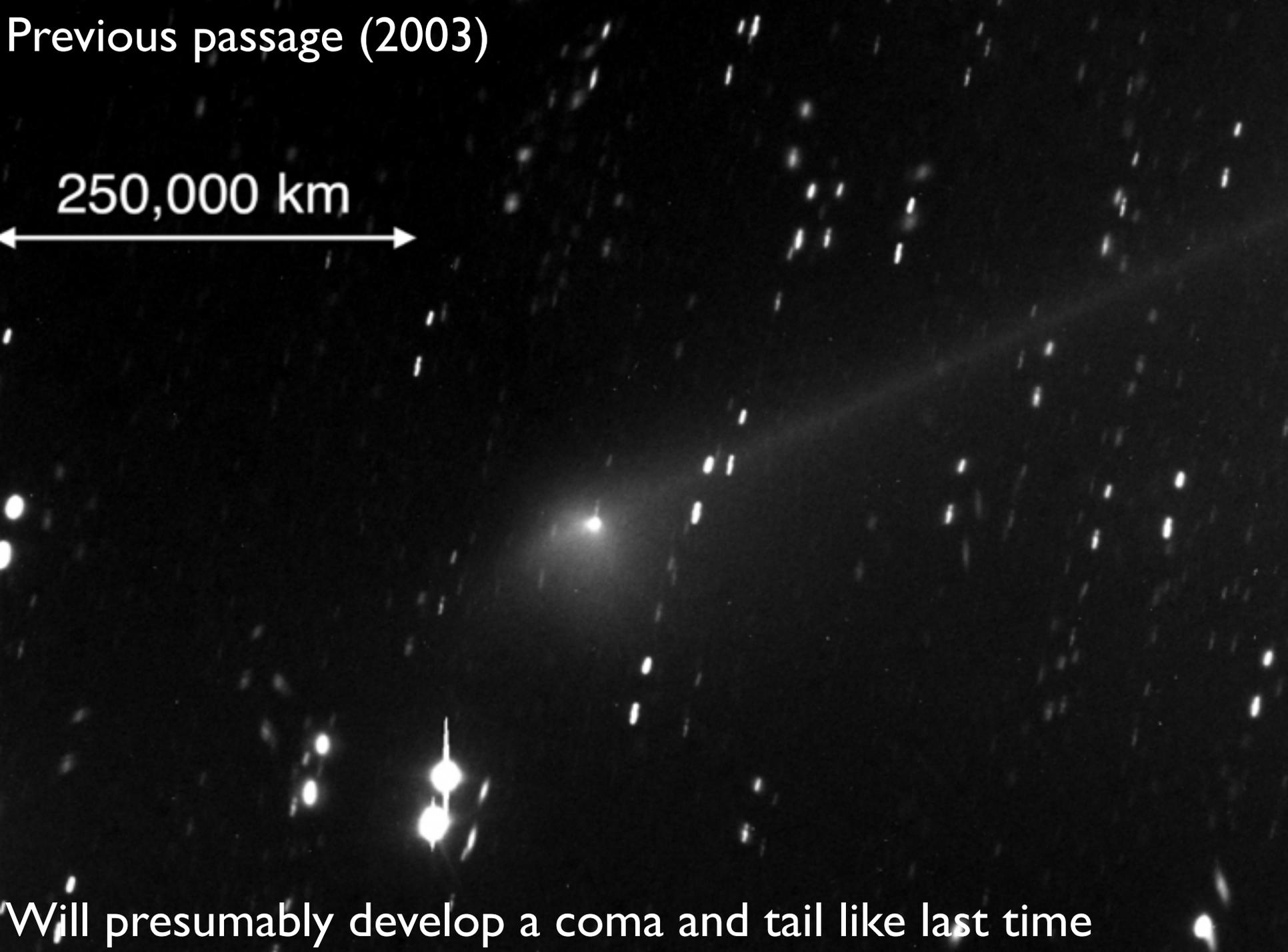
Nov 13, 2014

Previous passage (2003)

250,000 km



Will presumably develop a coma and tail like last time



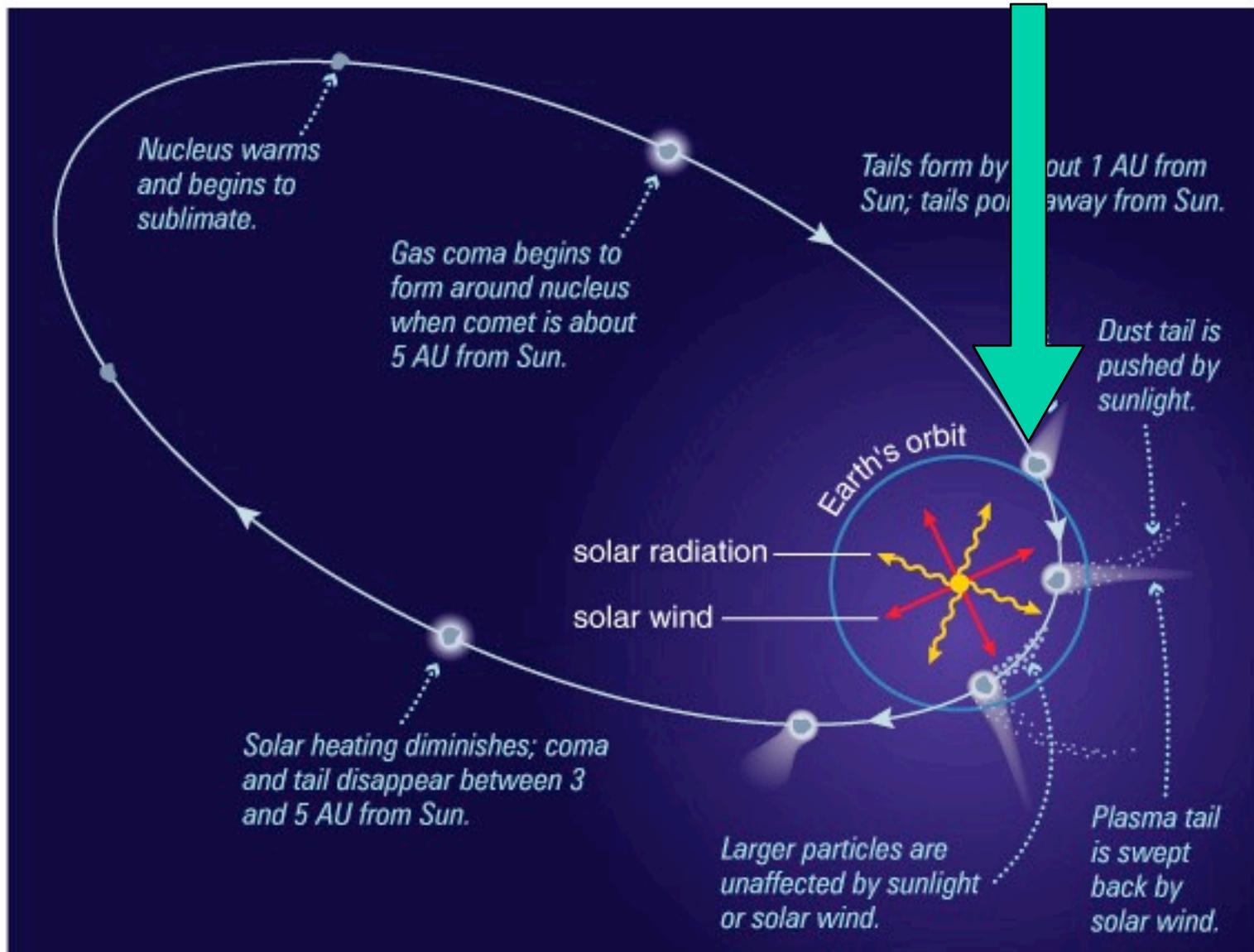
Comet debris: meteoroids



Comets eject small particles (**meteoroids**) that follow the comet around in its orbit and cause meteor showers when Earth crosses the comet's orbit.

Annual meteor showers

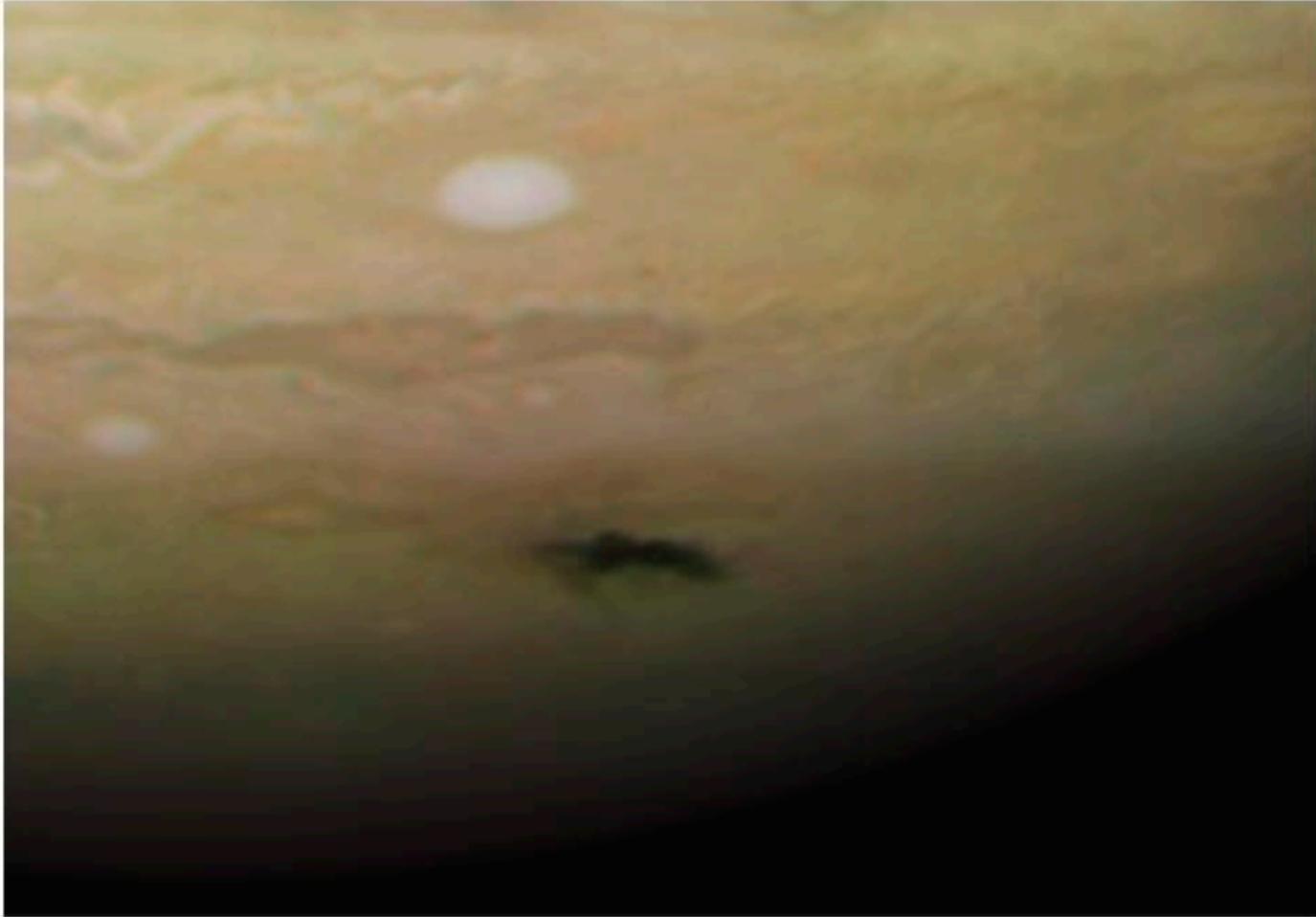
Happen when Earth's orbit intersects a comet's orbit strewn with meteoroids

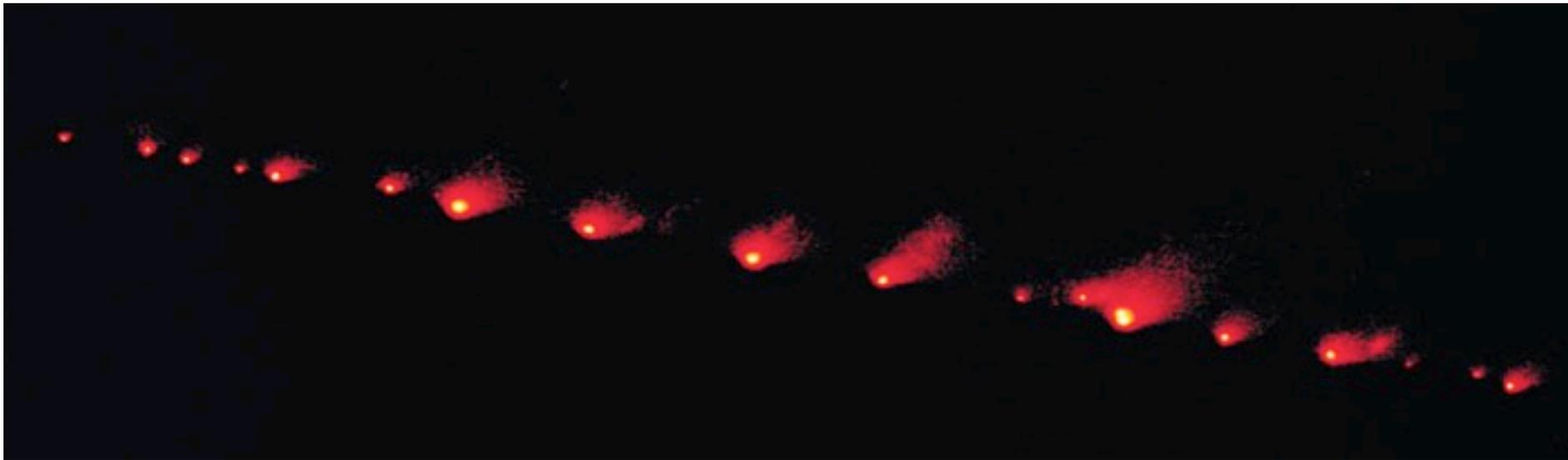


Big meteor
shower:
Comet 67P
compared
to Boston



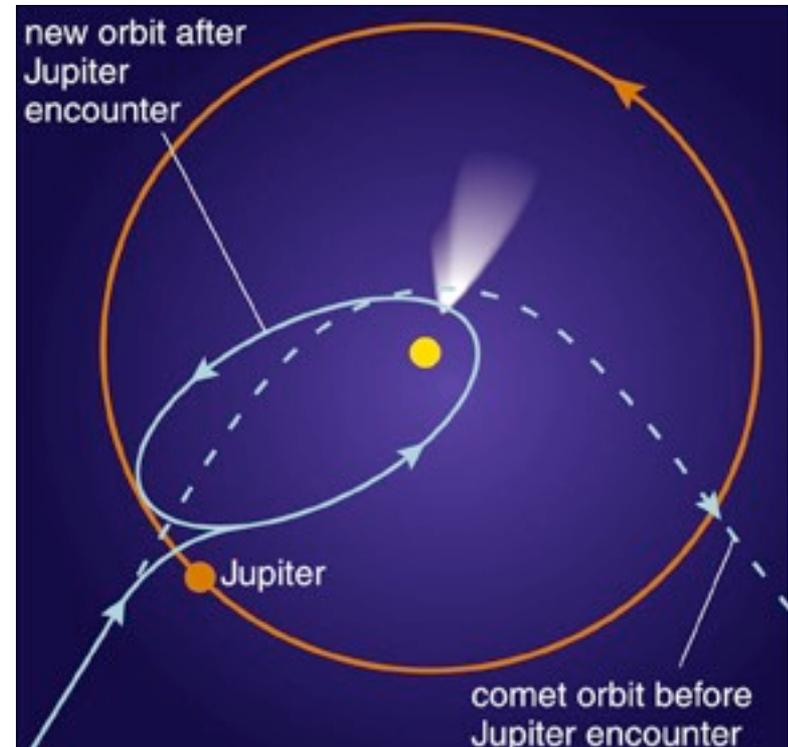
Have we ever witnessed a major impact?

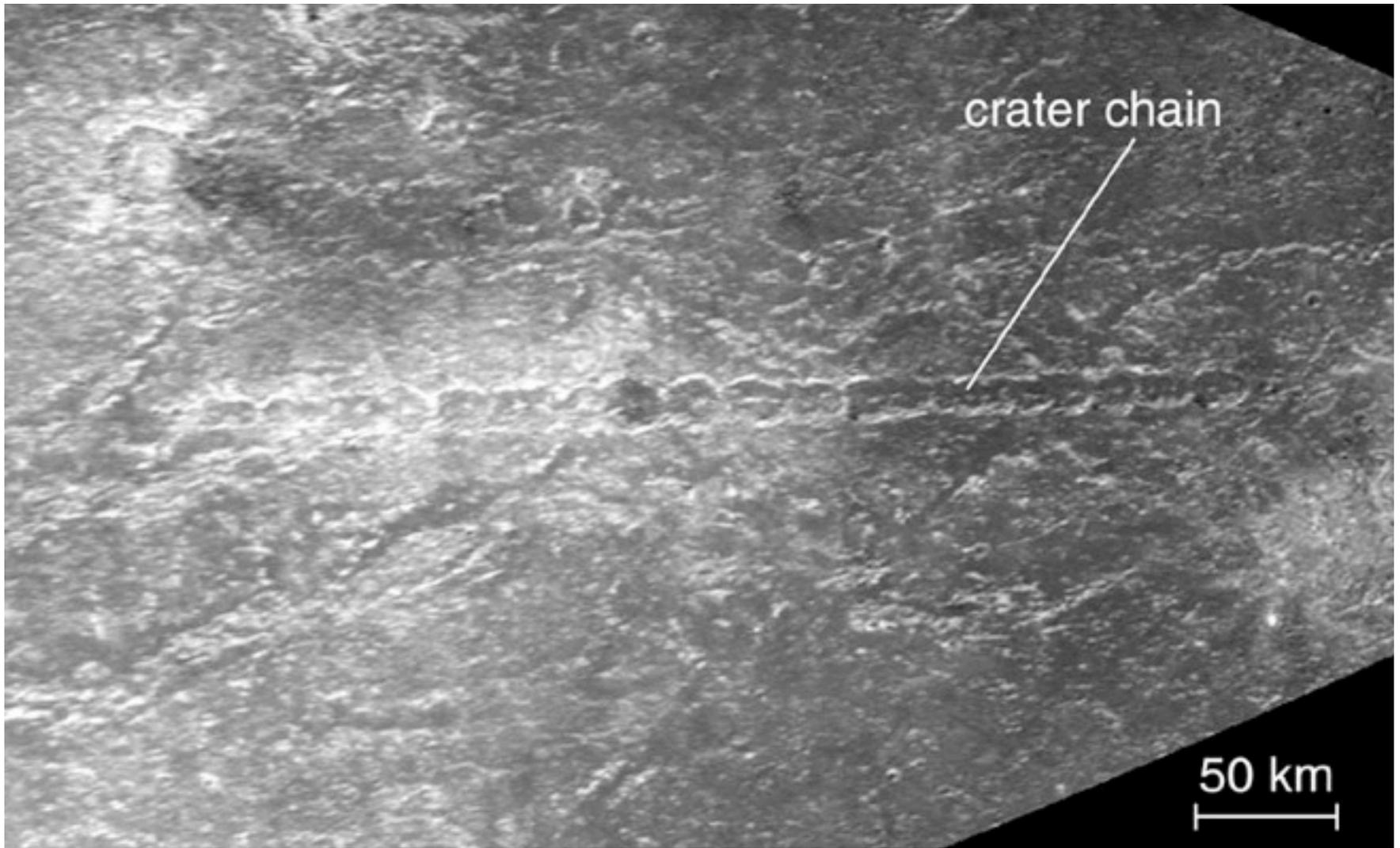




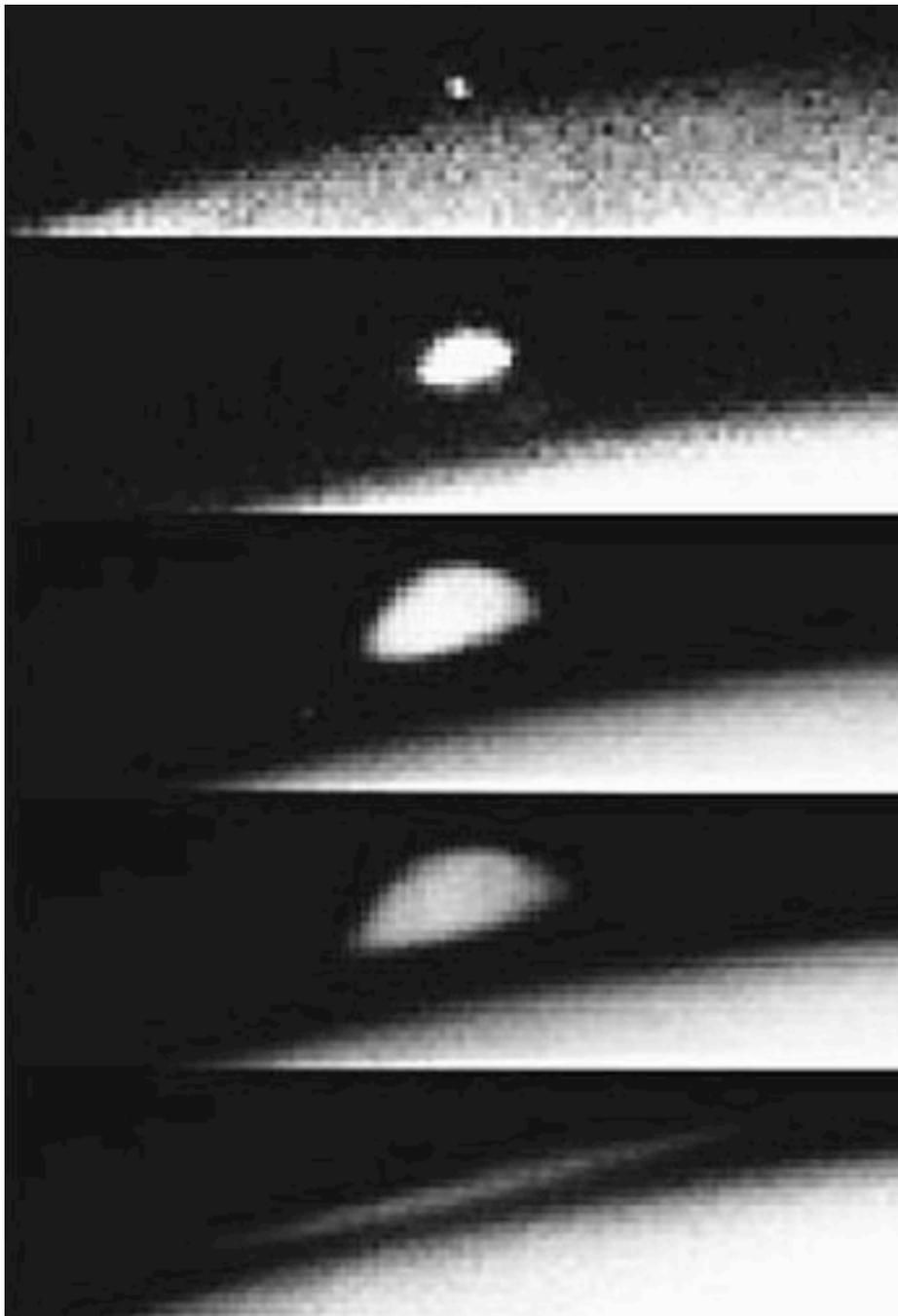
Comet SL9 caused a string of violent impacts on Jupiter in 1994, reminding us that catastrophic collisions still happen.

Tidal forces tore it apart during a previous encounter with Jupiter.





This crater chain on Callisto probably came from another comet that tidal forces tore to pieces.

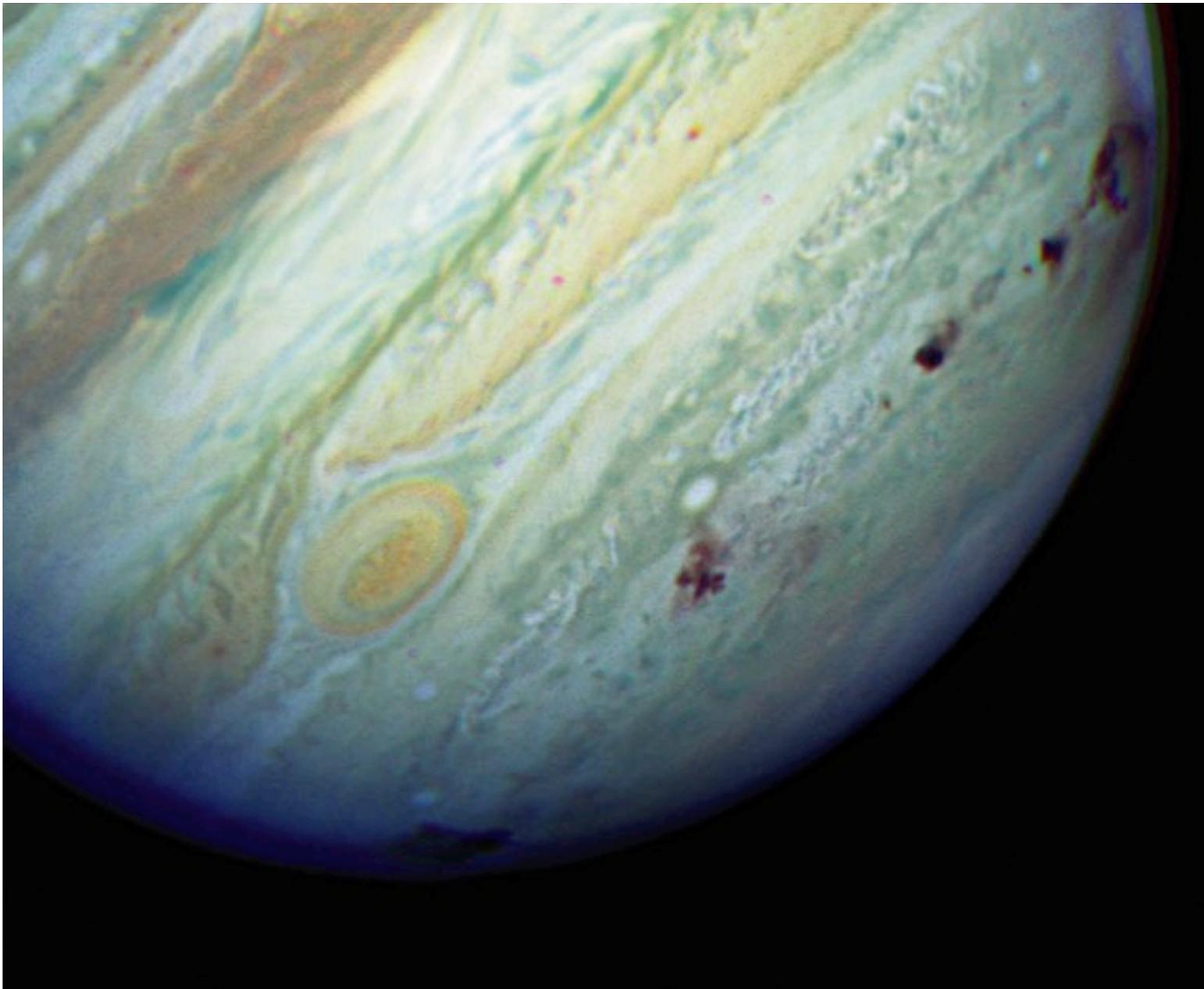


Impact plume
from a fragment
of comet SL9
rises high above
Jupiter's surface

See movies in
`/Users/ssm/Documents/Courses/
UMd/misc_movies/cometSL9`



Impact sites in infrared light

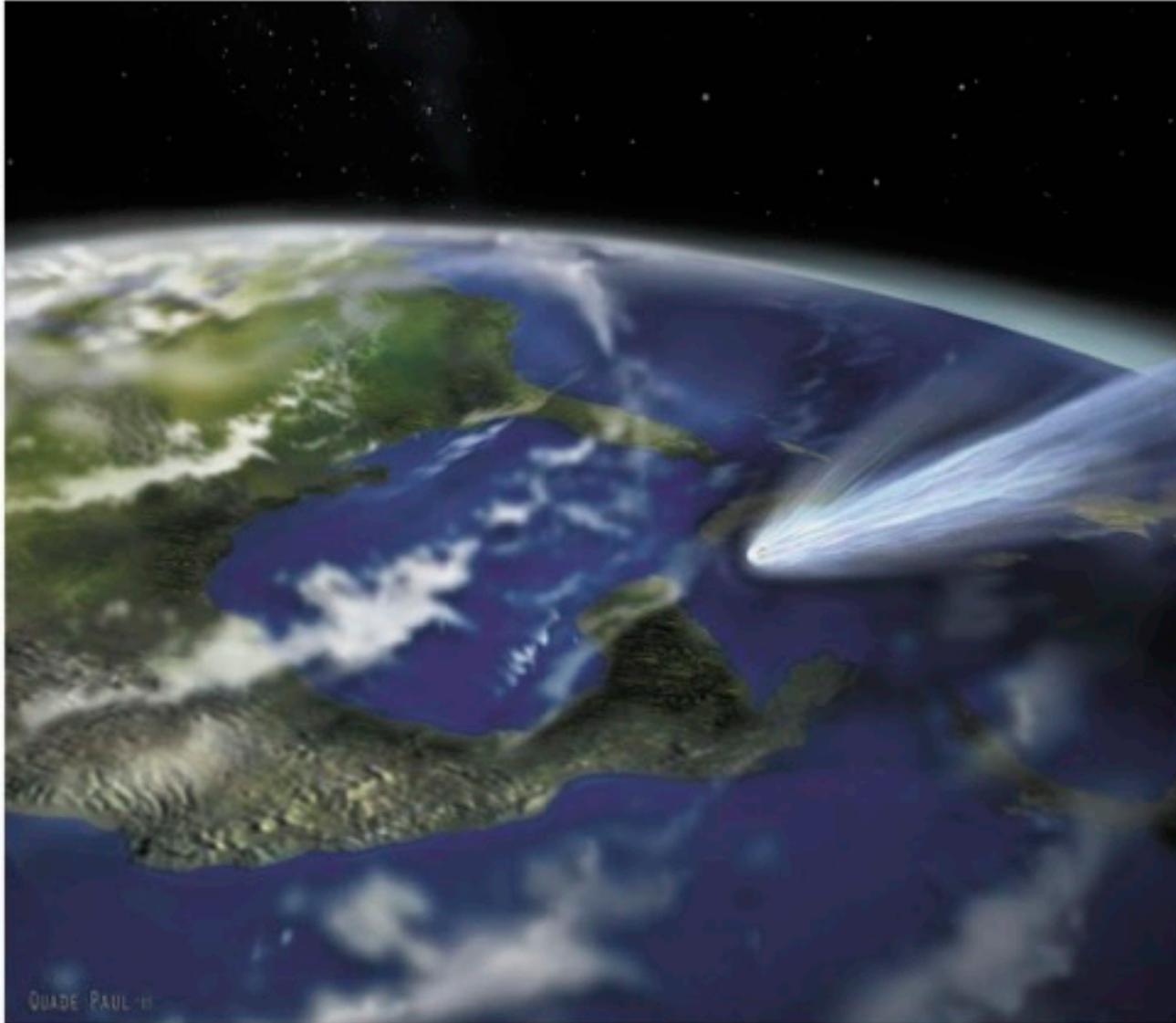


Several impact sites

Facts About Impacts on Earth

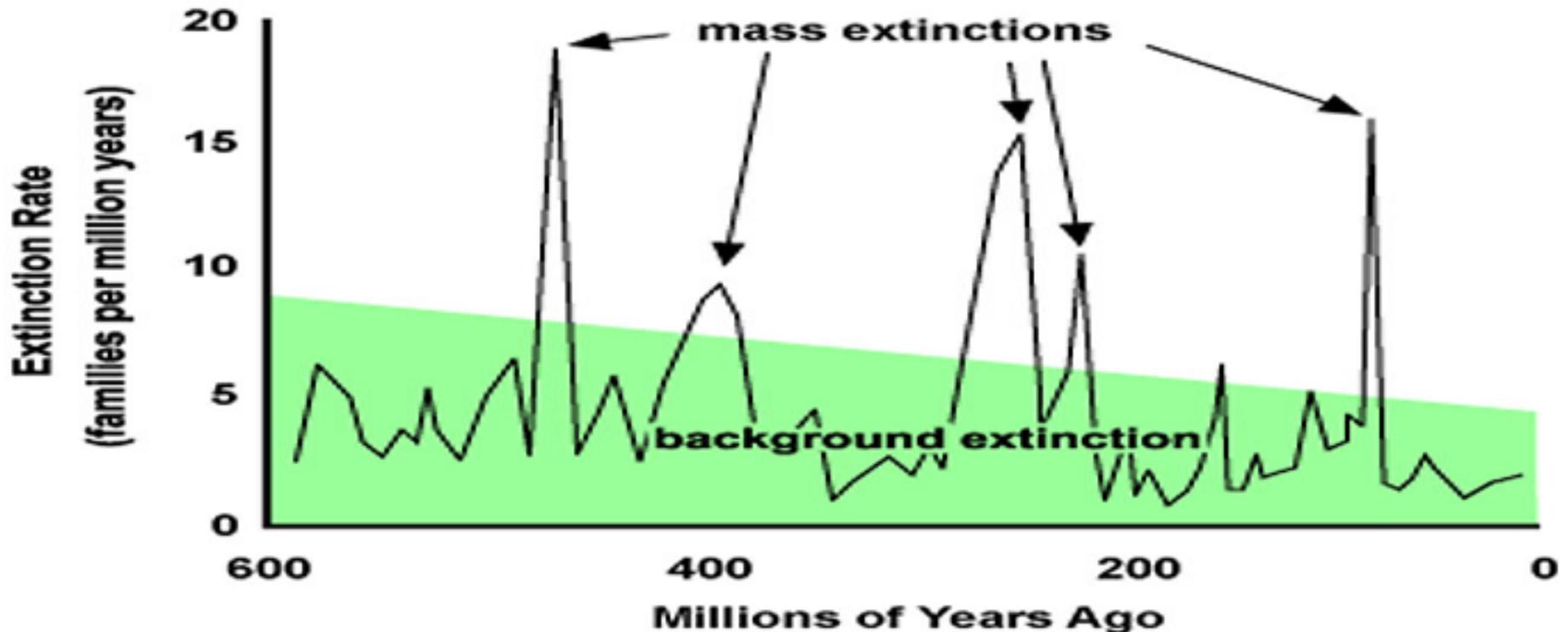
- Asteroids and comets have hit the Earth.
- A major impact is only a matter of time: not IF but WHEN.
- Major impacts are very rare.
 - A major impact is thought to have contributed to the extinction of the dinosaurs 65 Myr ago.
- Something large enough to harm a city might occur every century or so.

Did an impact kill the dinosaurs?



Mass Extinctions

- Fossil record shows occasional large dips in the diversity of species: *mass extinctions*.
- Most recent was 65 million years ago, ending the reign of the dinosaurs.



Iridium: Evidence of an Impact

- Iridium is very rare in Earth surface rocks but often found in meteorites.
- Luis and Walter Alvarez found a worldwide layer containing iridium, laid down 65 million years ago, probably by a meteorite impact.
- Dinosaur fossils all lie below this layer.

irridum is rare at the surface of the earth because it is dense; presumably most of it differentiated into the core. Hence an irridium rich layer implies an injection of material from space.

Iridium Layer

No dinosaur fossils in upper rock layers

Thin layer containing the rare element iridium

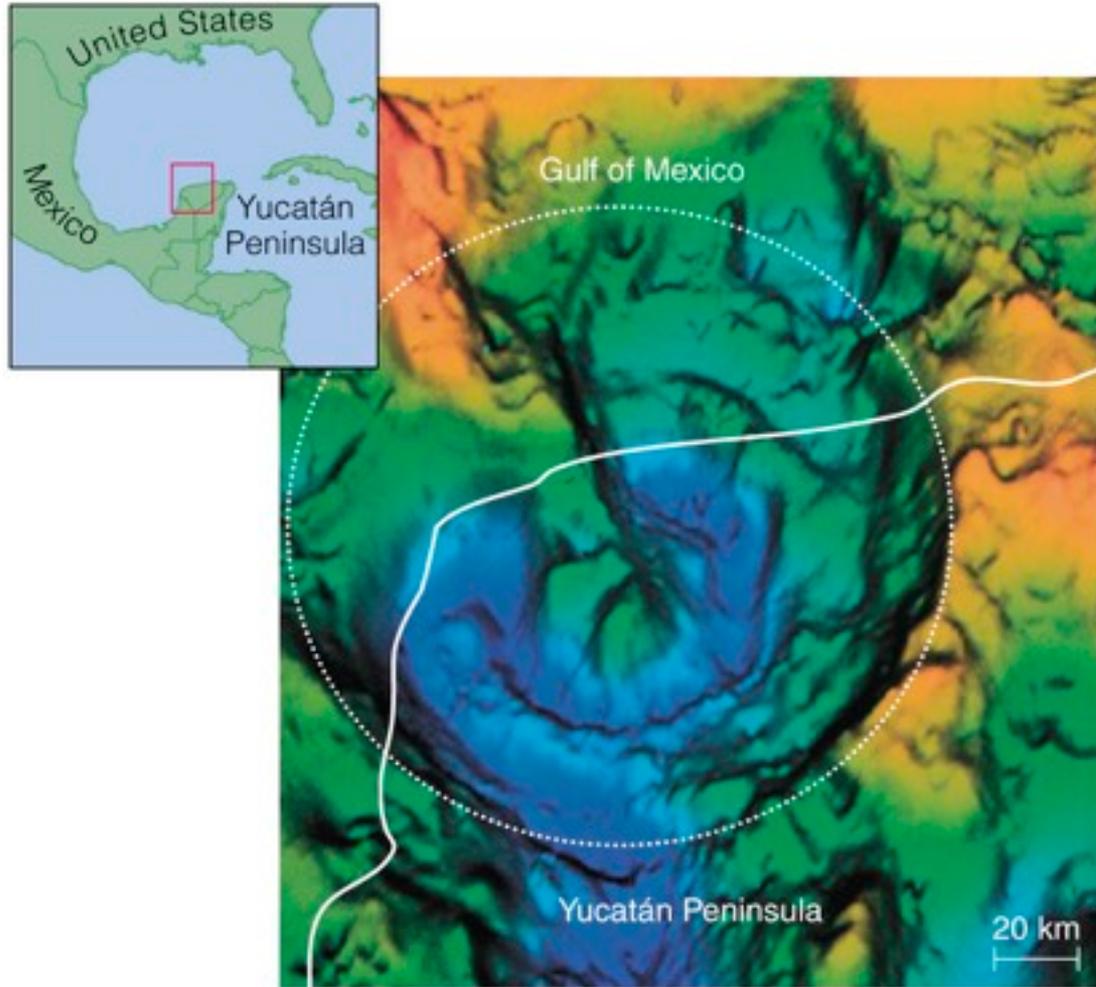
Dinosaur fossils in lower rock layers



Consequences of an Impact

- Meteorite 10 kilometers in size would send large amounts of debris into atmosphere.
- Debris would reduce sunlight reaching Earth's surface.
- Resulting climate change may have caused mass extinction.

Likely Impact Site



- Geologists have found a large subsurface crater about 65 million years old in Mexico.
- There is evidence of flooding debris 100s of km inland from gulf coast

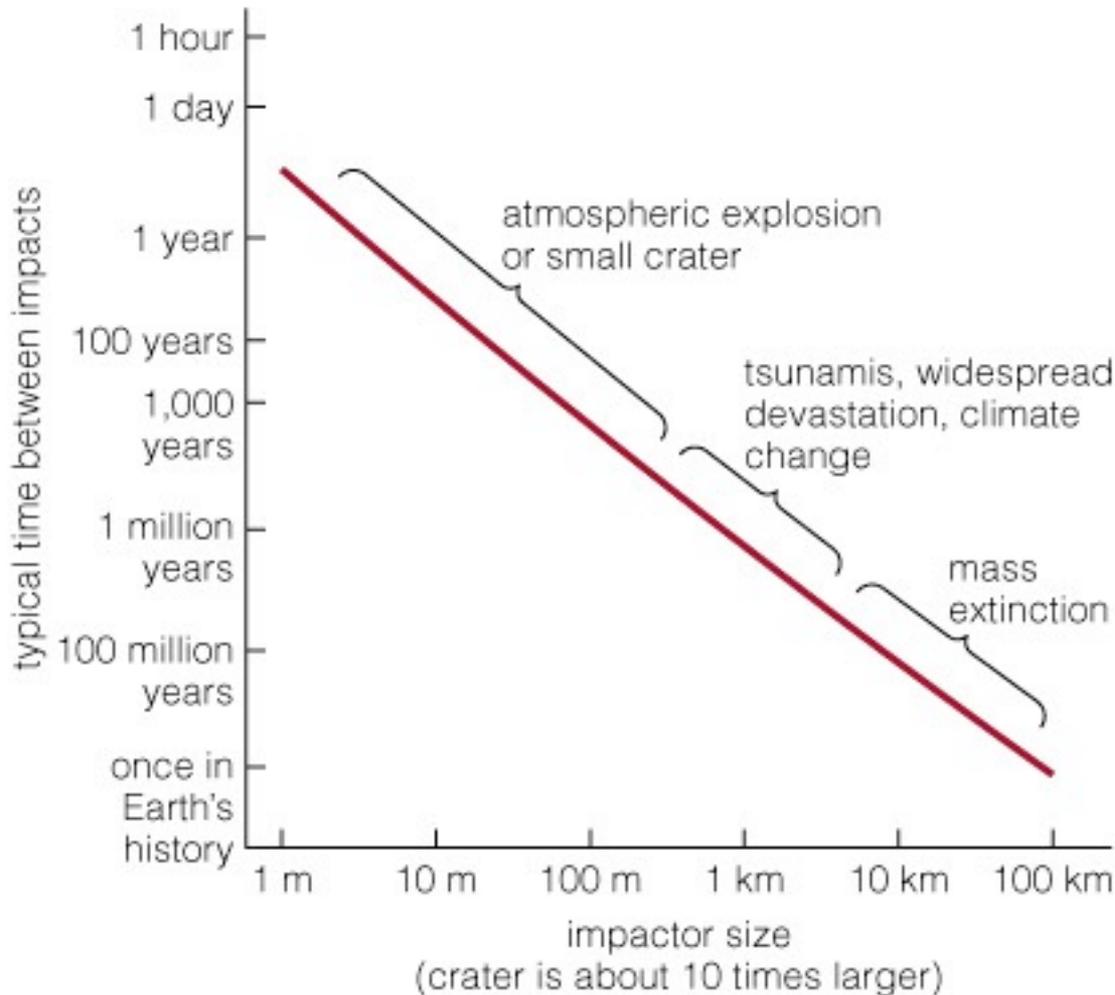
Chelyabinsk (Feb 15, 2013)

A ~20 meter object disintegrated and exploded in the atmosphere



<https://www.youtube.com/watch?v=dpmXyJrs7iU>

Frequency of Impacts



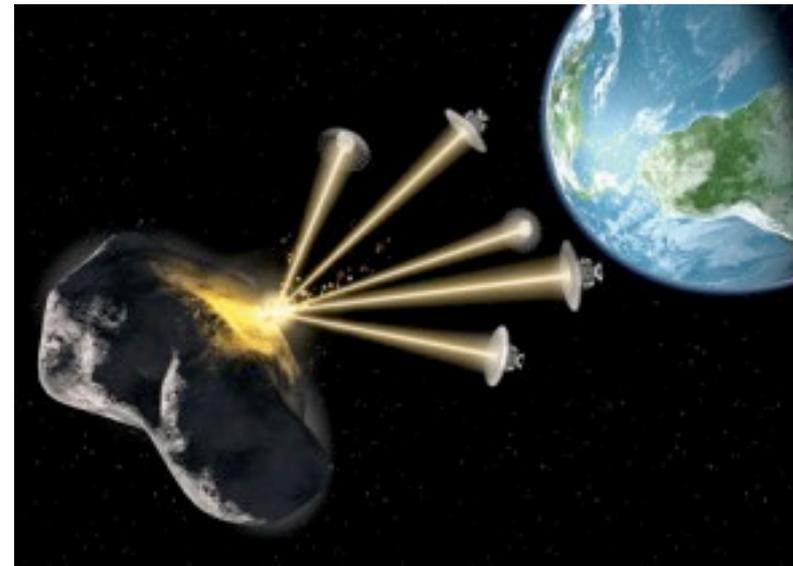
- Small impacts happen almost daily. – meteors!
- Impacts large enough to cause mass extinctions are many millions of years apart.

Asteroid/Comet Deflection

- Deflection is challenging; the more advance warning the better.
- Breaking a big asteroid into a bunch of little asteroids does not really help.
- Best chance is to nudge the orbit a bit.



gravity
tug



solar sublimation